JOURNAL of THE IRON AND STEEL INSTITUTE

VOL. 162 PART 2

JUNE 1949

Editor
K. HEADLAM-MORLEY

Managing Editor
E. R. MORT, B.Sc., F.I.M.

Technical Editor
A. E. CHATTIN, B.Sc., A.R.I.C., F.I.M.

Assistant Editor
C. R. HARMAN, B.Sc.(Eng.)

PUBLISHED MONTHLY

Editorial contents copyright by THE IRON AND STEEL INSTITUTE

SUBSCRIPTIONS

Members : Free
Extra Copies 7s. 6d. each

Non-Members : £5.0.0 per annum
Single Copies 10s. each

EDITORIAL AND ADVERTISEMENT OFFICES

4, Grosvenor Gardens, London, S.W.1

Telephone : SLOane 0061. Telegrams : Irosamente, Sowest, London

CONTENTS

IRON AND STEEL INSTITUTE PAPERS

"Electrochemical Studies of Protective Coatings on Metals.
Pt. I.—Electrode Potential Measurements on Painted Steel" *by F. Wormwell and D. M. Brasher* ... 129

"Recent Steelplant Developments at the Appleby-Frodingham Steel Company" *by A. Jackson* ... 136

DISCUSSION ON PAPERS

Autumn General Meeting, 1948—
Discussion on the Cowper Stove ... 163
Discussion on Magnetic Concentration Experiments ... 166
Discussion on a Statistical Department in Heavy Industry ... 172
Discussion on Oxygen Enrichment in the Side-Blown Converter ... 175

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

"Studies on Anti-Fouling Compositions—
Pt. VI.—The Leaching Rate During the Early Stages and its Relation to the Surface Conditions in Cuprous Oxide Compositions" *by H. Barnes* ... 179

"A Note on the Metering of Crude Producer Gas in a Horizontal Main" *by W. G. Cameron* 185

"Plastic Strain and Hysteresis in Drawn Steel Wire" *by R. S. Brown* ... 189

IRON AND STEELWORKS ENGINEERING

"Continuous Steel Strip Pickling" *by R. W. Treasure* ... 201

"The Disposal of Spent Acid Pickling Liquor" *by W. B. Wragge* ... 213

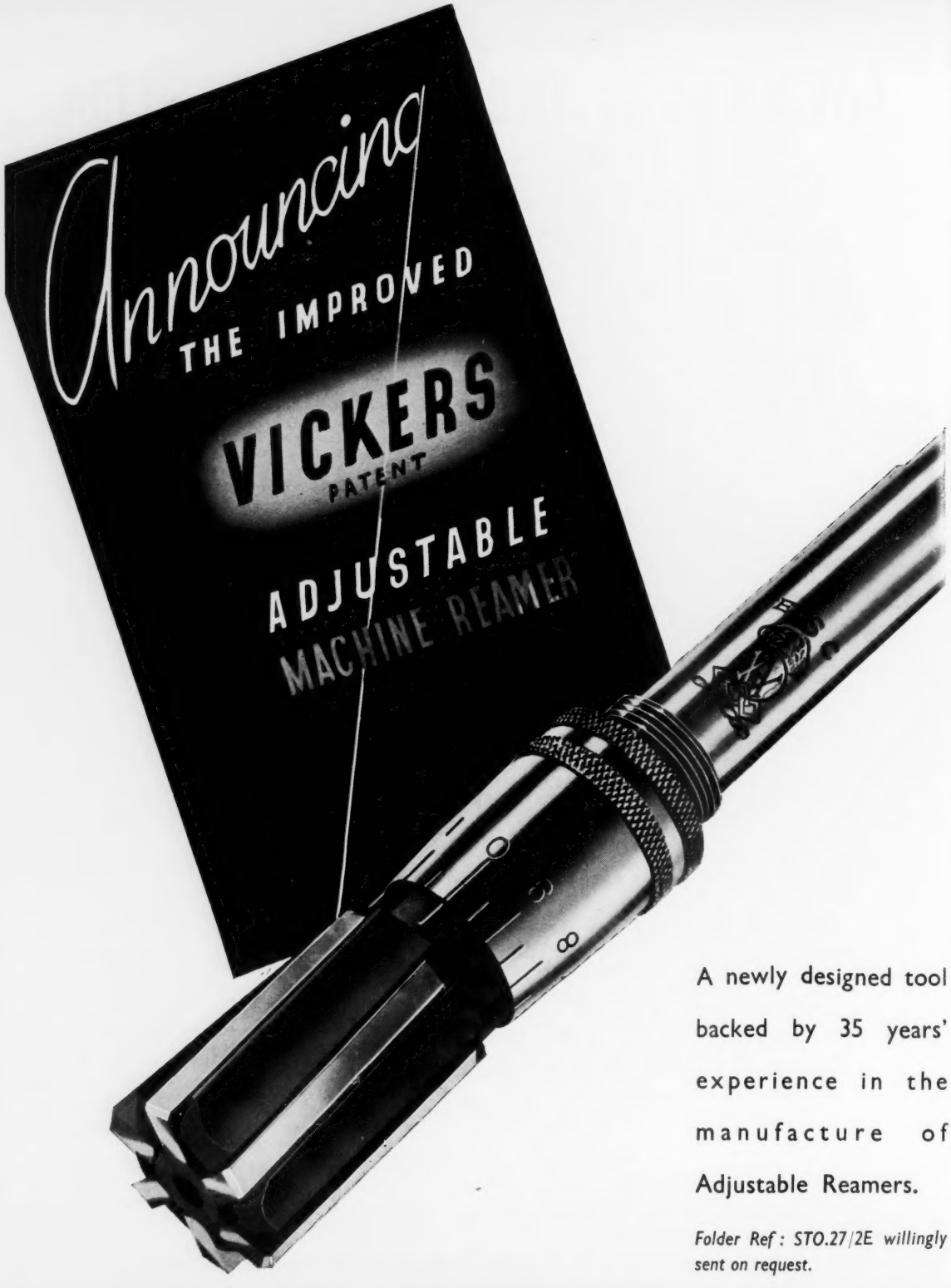
NEWS

Annual General Meeting, 1949 ... 225
Autumn General Meeting, 1949 ... 225
Changes on Council ... 225
News of Members ... 225
Contributors to the Journal 226
Iron and Steel Engineers Group ... 227
Affiliated Local Societies ... 227
News of Science and Industry 227
Diary ... 228
Translations ... 228

ABSTRACTS and BOOK NOTICES

Contents ... 229
Abstracts ... 229-246
Book Notices ... 246
New Publications ... 248

NOTE : The Institute as a body is not responsible for statements made, or opinions expressed, in papers, articles, or discussion appearing in the Journal of The Iron and Steel Institute.



A newly designed tool backed by 35 years' experience in the manufacture of Adjustable Reamers.

Folder Ref : STO.27/2E willingly sent on request.

ENGLISH STEEL CORPORATION LTD
OPENSHAW MANCHESTER

SIR JOHN GREENLY, K.C.M.G., C.B.E., M.A.

JOHN HENRY MAITLAND GREENLY was born in 1885. He was educated at Charterhouse and Trinity College Oxford, and subsequently trained as a Civil Engineer with Sir John Wolfe Barry and Partners. Commissioned in the Herefordshire Regiment, (T.F.) in 1906, he served in the Great War (1914-1918), and twice was mentioned in despatches. He was promoted to Lieutenant-Colonel in 1917. In the latter part of the war he was appointed Assistant Controller of Inspection of Munitions of War at the Ministry of Munitions, and received the C.B.E. in 1919.

In 1920 he became Joint Managing Director of Messrs. William Foster, Pascoe, Grenfell and Co., copper manufacturers and smelters, and subsequently Joint Managing Director of British Copper Manufacturers, Ltd. He became a Director of Messrs. Babcock and Wilcox, Ltd., in 1929, and served as Chairman of the Executive Committee; in 1932 he was appointed Deputy-Chairman of the Company, and became Chairman in 1937.

Sir John became Chairman of the British Non-Ferrous Metals Research Association in 1937, and was a member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research from 1937 to 1943 ; he also served from 1938 to 1939 as a member of the Industrial Advisory Panel to the Air Ministry, and as Chairman of the Prime Minister's Advisory Panel of Industrialists on Re-armament. From 1939 to 1940 he acted as Controller-General of the British Supply Board in Canada and U.S.A. ; in 1941 he became Deputy Chairman and Administrator of the National Fire Prevention Executive, and in the same year was created K.C.M.G. for public services, both in this country and abroad.

Among the offices held by Sir John, the following may be mentioned : Director of Power Securities Corporation, Ltd. ; Director of Cape Asbestos Company, Ltd. ; Past-President and Fellow of the Institute of Metals ; Past-President and Fellow of the Institute of Fuel ; Member of Council of the British Welding Research Association ; Member of Council (Past-President) of the Institute of Engineering Inspection ; Member of Council (Past-President) of the Combustion Appliance Makers' Association ; Chairman of the Coal-Burning Appliances Joint Consultative Board ; Vice-President of the Coal Utilization Joint Council ; Member of Council of the British Coal Utilization Research Association ; Member of the Fuel Research Board, 1942-1947 ; Member of the Fuel and Power Advisory Council, 1944-1946. He was elected an Honorary Vice-President of The Iron and Steel Institute in 1944. He is also a member of The Institution of Mechanical Engineers.

Sir John Greenly, K.C.M.G., C.B.E., M.A.
Honorary Vice-President

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Electrochemical Studies of Protective Coatings on Metals

By F. Wormwell, M.Sc., Ph.D., and D. M. Brasher, B.Sc., A.R.I.C.

PART I—ELECTRODE POTENTIAL MEASUREMENTS ON PAINTED STEEL

SYNOPSIS

A description is given of an experimental technique for measuring changes with time of the electrode potential of painted steel immersed in artificial sea-water. It has been shown that, by continuing the observations over longer periods than have been used by earlier workers, the electrical measurements can be closely correlated with the rate of breakdown of the paint as estimated visually and also by determinations of weight loss of the underlying metal. The technique has been used to investigate the effect of paint thickness, the type of surface finish, the method of pretreatment before painting, and the type of paint.

THERE is a recognized need for improved methods of assessing quantitatively the period of initial breakdown of paint systems on metals and also the extent of failure after a prescribed exposure period. In accelerated corrosion tests in immersed conditions at the Chemical Research Laboratory, the extent of breakdown of paint coatings has usually been estimated visually, this method being occasionally supplemented by measurements of weight loss or depth of corrosion pits in the metal, after the removal of paint and corrosion products. It has nevertheless been felt desirable to develop a more sensitive method of detecting changes in the properties of painted metal surfaces and to evolve a technique that would yield quantitative results free from personal errors such as arise in using visual methods of examination. The first technique selected was the measurement of electrode potentials of painted specimens immersed in artificial sea-water, a method introduced by Burns and Haring,[1] and subsequently used by many investigators.[2–8] The results of these earlier workers may be summarized as follows. Potential/time curves can frequently be related to the corrosion behaviour of painted metal surfaces immersed in a corroding medium, in the sense that rising potentials indicate passivity and falling potentials denote activity. The work has, however, revealed many inconsistent phenomena requiring *ad hoc* explanations. The modified technique of Haring and Gibney,[5] in which the electrode potential measurements are made on specimens in a nitrogen atmosphere, appears to be fundamentally unsound, as is also their practice of attempting to correlate behaviour under atmospheric conditions with potential changes in immersed conditions.

From a study of the earlier work it was concluded that further examination of the electrode potential technique was required before it could be used with confidence in assessing the protection afforded by paint coatings on metals in immersed conditions. The following account describes the study of potential/time curves over periods of time much longer than those used by earlier investigators. This has led to the recognition of the characteristic shapes of the curves and their relationship to the changes in condition of the protective coating on the metal.[9, 10] A further account will describe the extension of the work to measurements of electrical resistance and capacitance, a brief survey of which has been given elsewhere.[10]

Since this work was completed, Bacon, Smith, and Rugg[11] have described the use of an alternative electrical method of assessing the relative rates of breakdown of paints on steel immersed in sea-water. Although these authors present their results in the form of logarithm of resistance plotted against time, the values of resistance are calculated from measurements of electrode potentials of painted plates with

Manuscript received 19th October, 1948.
Dr. Wormwell and Miss Brasher are at the Chemical Research Laboratory, Department of Scientific and Industrial Research, Teddington, Middlesex.

reference to a standard calomel electrode. The actual measured potentials are not reported, and the authors do not describe the shape of the potential/time curves obtained.

EXPERIMENTAL TECHNIQUE

Preliminary experiments were carried out by Dr. J. Sheridan, using mild-steel specimens 1-in. square, cut from weathered ships' plate, the surface being pickled and wire-brushed before painting. From the poor reproducibility of the results and the absence of correlation between the visual behaviour and the type of potential/time curve, it was concluded that the controlling factor was the inhomogeneity of the surfaces tested. The original surfaces were covered partly with mill scale and partly with rust, the rusted areas producing a rougher surface after pickling. This was particularly important with painted specimens, since the rough areas caused local weakness in the paint, leading to earlier breakdown. It was decided that machined surfaces (as described later) should be used in future work. Apart from improving the uniformity of surface condition, it appeared desirable to increase the size of the specimens in order to smooth out the effect of minor variations in the metal and the paint film.

Preparation of Specimens

Specimens, $3\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{8}$ in., were cut from mild-steel ships' plate, received initially in the partly 'weathered' condition. For certain comparative tests (*see* p. 131) the paint was applied to the surface after wire-brushing and degreasing only; in other work the metal was pickled in 15% sulphuric acid (inhibited with 0·05% di-orthotolylthiourea) at 40° C., then washed in water, dried, and finally wire-brushed. Most experiments were conducted on specimens finished on an emery belt No. 0 (using a 'linisher' machine) or ground on a precision grinder with wheel P (medium-soft). Unless otherwise stated, all specimens were degreased in liquid benzene (two baths at room temperature) or in benzene vapour, and stored in a desiccator for at least 12 hr. before use.

Description of Paints

Since the present investigation is not concerned with the influence of paint composition as such, but only with methods of testing, *i.e.*, performance tests, it is unnecessary to give complete details of paint formulation. These factors will be discussed in a further communication. For the present work a typical ships' bottom composition system, paint *A*, of only moderate quality (based on service experience and on results of rotor tests[12]), was chosen, in order to facilitate rapid assessment of paint failure. The anti-corrosive paint consists of iron oxide and other minor pigments, such as titanium oxide, in a resin/linseed-oil medium. The anti-fouling coat was omitted in order to avoid complications due to the presence of mercury and copper. A few comparative tests have been conducted on paint *B*, of similar general type to *A*; also on paint No. 173, as formulated by Fancutt and Hudson[13] for the British Iron and Steel Research Association. This paint (pigmented with basic lead sulphate, white lead and Burntisland red in a modified phenol-formaldehyde-resin/stand-oil medium) has given very good results in raft tests and in accelerated laboratory rotor tests. Finally, some work has been done with an experimental paint *E* (2), made up from leaded linseed stand oil with red iron oxide as the main pigment. Modifications of this paint are being tested, with a view to formulating a simple 'control' paint of known composition that will fail fairly rapidly but in a reproducible manner. The paint could then be used for rapid tests of pretreatment methods designed to improve paint adhesion.

Painting Procedure

During painting, the specimens were held vertically in a rack, arranged to grip the specimens along the bottom edge only, leaving the whole test area freely exposed. For each coat a controlled volume (2·6 ml.) of paint (equivalent to the amount per unit area used in rotor tests[12]) was applied with a $\frac{3}{4}$-in. bristle brush over each pair of specimens, which were weighed initially and after the final painting. The average weight of two coats of dry paint for a typical paint *A* was 25 mg./sq. in.,* the estimated standard deviation being 2·1 mg./sq. in. An interval of approximately 24 hr. was allowed after the first coat, and 20 to 24 hr. after the second coat, before immersion. (When a third coat was applied, the second was allowed 24 hr. for drying, and the third 20 to 24 hr.).

Preparation of Artificial Sea-Water

Since the initial objective was to investigate the protective properties of paints intended for application to ships' hulls, the corroding medium chosen for all the tests was sea-water (artificial). The following figures show the composition of the solution, which contains all the principal ions present in the natural water:

Composition of Artificial Sea-Water

Salt	Wt. of Anhydrous Salt per Litre of Solution, g.
NaCl	27·26
$NaHCO_3$	0·11
KCl	0·69
KBr	0·09
$CaSO_4$	1·29
$MgCl_2$	3·51
$MgSO_4$	1·84

The *p*H of the solution after thorough aeration and stirring at 25° C. varied from 8·1 to 8·2, and after use in a test the *p*H was usually 8·0 to 8·1.

Experimental Procedure

A diagram of the apparatus is given in Fig. 1. Specimens were suspended by means of a steel rod screwed in to the upper edge of the specimen, the lower 3-in. length of the rod being covered with a sleeve of glass tubing. The junction of the tubing and the specimen, also the edges of the specimen to a distance of $\frac{1}{4}$ in. into each face, were heavily coated with a gutta-percha/paraffin-wax mixture, leaving a total area of 12 sq. in. exposed on each specimen. Ebonite lids, fitting into the tops of tall 2-litre resistance glass beakers ($4\frac{1}{2}$ in. dia.) held the

* This corresponds to a paint thickness of approximately 0·007 cm. (70μ).

specimens centrally in a vertical plane at a depth of 1½ in. below the surface of the liquid (1500 ml.). A slot, cut in the edge of the lid for the insertion of a capillary-tubing liquid bridge, also allowed access of air to the corrosion vessel. Under these conditions evaporation was very slow (approximately 1% of the total volume per month). Usually no attempt was made to restore the level of the liquid, since in some early experiments it was found that the addition of distilled water, without stirring (which is undesirable since it disturbs corrosion products), had a considerable effect on the shape of the potential/time curves owing to an increase in the rate of supply of oxygen to the metal surface produced by convection currents. The sea-water was not usually changed during a test; special experiments showed that changing the water did not affect the general shape of the potential/time curves, although the deterioration of the paint was slightly accelerated.

Several units were connected by individual liquid bridges *via* an intermediate vessel to the same calomel half-cell. Experiments were carried out at least in duplicate. No automatic temperature control system has been used, but variations in the room (free from draughts and direct sunlight) do not generally exceed 3° to 4° C. over long periods. The temperature was recorded at the time of each reading. Specimens were re-weighed at the end of a test, following the removal of the paint and wax in hot benzene, and of the rust by cathodic treatment in 10% ammonium citrate solution at a current density of approximately 2 amp./sq. dm. The total amount of corrosion was measured by the loss of weight of metal. During the test, visual estimates were made of the percentage area affected by rusting; these gave *comparative* figures for the progress of paint failure, although the actual area of metal exposed (and corroding) at any stage was appreciably less than the estimated 'area rusted,' owing to the spreading of the rust over the adjacent intact paint.

Electrode Potential Technique

Measurements of electrode potential were made with a valve potentiometer, as used by earlier workers.[1, 4, 7] Values are expressed (as measured) with reference to the 'saturated' calomel electrode (calomel/sat. KCl), and represent the 'compromise' potential[14] of the whole specimen.

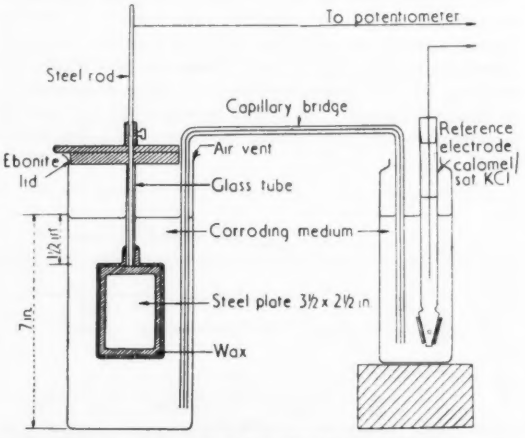


Fig. 1—Apparatus for electrode potential measurements

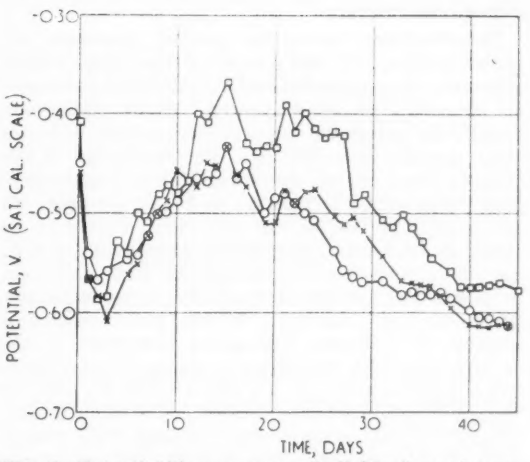


Fig. 2—Potential/time curves. Individual specimens, emeried surfaces, anti-corrosive paint *A*

EXPERIMENTAL RESULTS

Unpainted Specimens

As a basis for comparison with measurements on painted specimens, the electrode potential of unpainted steel was measured over a period of two days (13 days for 'weathered'* specimens). The potentials fell rapidly during the first half-hour or so, and very slowly thereafter, reaching constant values after about 24 hr. (after 6 days in the case of the weathered specimens). The following data give the 'initial' potential values (after 30 sec. immersion), and the final constant values obtained, for different types of surface preparation:

Influence of Surface Preparation on Electrode Potential of Unpainted Steel

Surface Preparation	Potential (sat.-cal. scale), V. 'Initial'	Final
Pickled	−0·45	−0·71
Ground	−0·49	−0·73
Emeried	−0·51	−0·735
'Weathered'	−0·39	−0·675†
Shot-blasted, phosphate-dichromate dip ...	−0·45	−0·74

The similarity in behaviour of ground and emeried surfaces is to be expected; the more noble behaviour of the pickled surface is possibly attributable to the removal of more reactive metal during preparation of the surface and, in the case of weathered specimens, to the presence of an adherent layer of rust which partially restrains the anodic reaction.

* The 'weathered' plate was covered with an adherent, but discontinuous, layer of mill scale, with rust in the discontinuities. Before the plate was used, the loose rust was removed by wire-brushing.

† A duplicate specimen showed erratic behaviour after 7 days, the potential suddenly rising and remaining roughly constant at about −0·6 V.

Painted Specimens

Potential/time curves for painted specimens are shown in Figs. 2, 3, and 5 to 9 ; of these, Fig. 2 alone shows the potentials obtained on individual specimens (in order to show the maximum ' scatter ' observed ; usually the agreement between repeat tests is better than appears from Fig. 2). The remainder of the potential/time curves are averages for two (sometimes four) specimens. The curves in Fig. 2 for paint *A** are typical of the general behaviour observed ; an initial rapid decline in potential from about −0·2 V. to −0·4 to −0·55 V. during the first half-hour, is followed by a period (possibly of several days) of fluctuating potential. If the paint coating is capable of conferring substantial protection on the underlying metal, there is a gradual rise in potential to more noble values, *e.g.*, −0·45 to −0·4 V., followed by a decline to values of around −0·6 V. Jarrett's results[7] include some curves showing this general form, but he makes no comment on this appearance of a ' hump ' in some of the curves. The significant observation is the *period* at which the final decline commences, since this coincides with the appearance of rust spots and other visual indications of paint deterioration.

The correlation between potential/time curves and the rate of corrosion of the underlying steel is illustrated in Fig. 3. The weight-loss and potential values were derived from a series of similarly painted plates (two coats of paint *A* on an emeried surface) immersed for varying periods up to 150 days. Potentials of each specimen were measured as usual, and at the termination of the appropriate period the specimens were freed from paint and rust, and re-weighed to determine the loss of metal.

The potential/time curve is based on the means of potential measurements on all the specimens used for the weight-loss determinations. This ' average ' potential/time curve shows clearly the characteristic changes which are partly obscured by random fluctuations on curves for individual specimens. The initial decline in potential is no doubt due to the rapid permeation of the paint film by water, oxygen, and dissolved salts, leading to slight attack on the metal. The recovery of the potential was at first attributed to the plugging of minute pores in the paint film by incipient rust. Dr. J. E. O. Mayne† has, however, suggested that it may be due in part, or wholly, to the inhibitive action of certain constituents of the paint. A full interpretation must await the results of further work on different types of paint.

The period at which the potential begins to decline (23 days) precedes by a few days the increase in corrosion rate. After about 50 days this rate is controlled by the rate of supply of dissolved oxygen to the surface of the specimen, but the area of breakdown of the paint (and rusting of metal) continues to increase slowly, as reflected in the continued decline of the compromise potential of the whole specimen. In Fig. 4 the rate of weight-loss, dW/dT, derived from the weight-loss/time curve of Fig. 3. is compared with the increase in the area rusted (as estimated visually) ; there is good general correlation between the two curves.

DISCUSSION

It is now clear why earlier investigators have been unable consistently to deduce, from observations over periods of a few days, the probable useful lives of paint coatings. In the first place, the potential changes during the first two days of immersion (not shown on the scale of Fig. 2) are less reproducible than the values for later periods. The present investigation has shown also that the potential is more liable to sudden fluctuations (and the values are again less reproducible) when the paint coating confers a relatively high degree of protection. This is true whether increased protection is achieved by applying a greater number of coats of a given paint, or whether a better quality paint is used (*see* Fig. 9). Similar observations have been recorded in conditions of protective film formation with stainless steels and with anodized aluminium (by one of the authors (F.W.), reported in unpublished work), and also with mild steel in solutions containing inhibitors.[15] Under such conditions accidental flaws in the protective film, or temporary breakdown of the film followed by repair, have a greater *relative* effect than in conditions of imperfect protection, where the addition of a few extra flaws has no material effect.

Better reproducibility is obtained with specimens pretreated with phosphoric acid before painting, possibly owing to a higher rate of passage of water through the paint on account of osmosis, or to improved wetting of the metal surface, or to a combination of the two causes. As would be expected, increasing smoothness of the metal surface also improves

* Unless otherwise stated, two coats of paint have been applied to all specimens.

† Private communication (17th September, 1948).

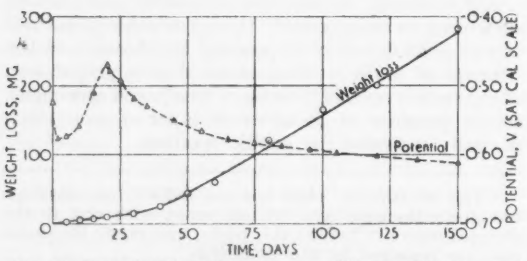


Fig. 3—Relationship between weight-loss/time and potential/time curves. Emeried surface, two coats of anti-corrosive paint *A*

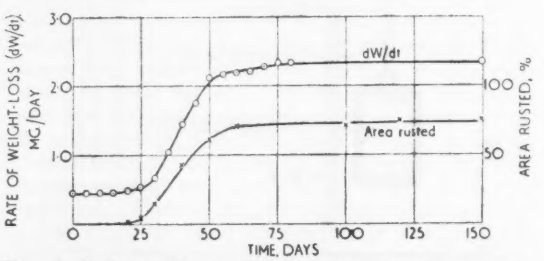


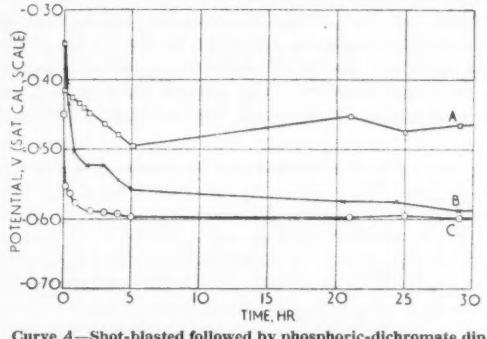
Fig. 4—Relationship between weight-loss/time and area-of-rusting/time curves

reproducibility, presumably owing to the less frequent occurrence of thin places in the paint coat on smoother surfaces.

Apart from difficulties due to lack of reproducibility, deductions from the potential measurements during the first two days may be misleading for the following reason. Although the potential/time curve, as a whole, almost invariably has the same general shape as that shown in Fig. 3, the changes occur much more rapidly with a paint which provides poor protection, or on a rough surface that militates against a uniform paint coating. The less protective the coating, the sooner will the maximum occur in the potential/time curve, so that an early rise in the curve is often indicative of indifferent protection. This is illustrated in Fig. 5, which shows the potential changes, during the first 30 hr. after immersion, on specimens representing three types of surface treatment of greatly differing protective value. In the light of conclusions reached by other workers,[1–8] treatment *A* would be judged to be the most effective, since the potential/time curve shows an upward trend (after the initial decline). Treatment *C* would be classed as the least effective, since the potential is lowest, and shows no tendency to rise. On continuing the tests, it was found that the ultimate behaviour was quite the reverse, as shown by the order in which the maxima on the curves were reached. Curve *A* (shot-blasted surface) passed through its maximum at 2 days, and extensive rusting had taken place within the first few days ; curve *B* (commercial phosphate treatment) passed through a maximum at 29 days, and curve *C* (10% phosphoric acid spray) at 38 days, with a corresponding delay in the period of rusting.

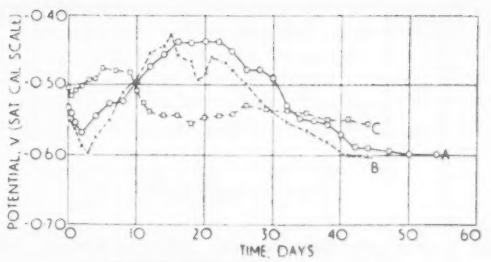
APPLICATIONS OF THE ELECTRODE POTENTIAL TECHNIQUE

It has been shown that, with the particular paint system used, the course of breakdown of the paint is reflected in the electrode-potential/time curve. The technique has accordingly been used to study the influence, on the rate of paint breakdown, of various factors such as the surface condition of the steel, the number of coats of paint, and finally the type of paint.



Curve *A*—Shot-blasted followed by phosphoric-dichromate dip
Curve *B*—Commercial phosphate treatment
Curve *C*—10% phosphoric acid spray

Fig. 5—Potential/time curves. Pretreated and painted surfaces



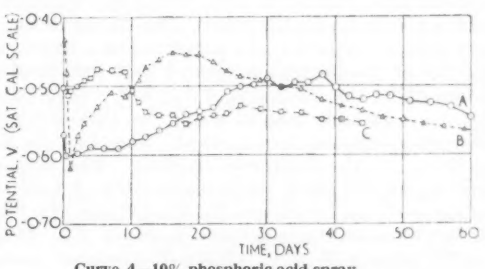
Curve *A*—Ground surface
Curve *B*—Emeried surface
Curve *C*—Pickled and wire-brushed

Fig. 6—Potential/time curves. Painted surfaces, anti-corrosive paint *A*

Influence of Surface Condition of Steel

Specimens with different types of surface were prepared by (*a*) grinding, (*b*) abrading on an emery 'linisher' belt, and (*c*) pickling and wire-brushing. (Details of these methods are given earlier in the paper.) The potential/time curves given by specimens painted with two coats of paint *A* are shown in Fig. 6. Visual observations showed that paint breakdown occurred most quickly on the pickled and wire-brushed surface (*C*) ; of the other two, the emeried surface (*B*) gave a slightly worse result than the ground surface (*A*). This behaviour is reflected in the general shape of the curves and, in particular, in the time required for the maximum to be reached in the three cases.

In other experiments the relative losses in weight, after 45 days' immersion, for specimens carrying the same thickness of paint (28 mg./sq. in.), were in the ratio of 129 (pickled) : 100 (emeried) : 88 (ground). The conclusions from the shapes of the potential/time curves thus agree with those based on measurements of weight loss of the steel. It is noteworthy that erroneous conclusions would be drawn if the behaviour of the three types of specimen were judged, as in previous methods,[1–8] from the early parts only of the curves (the first few hours or even days) ; the curve for the pickled specimen rises (after the initial decline), while the other two steadily fall for 2–3 days. The relative values of potential at the end of the tests (at some 40 days) are equally misleading from the standpoint of paint failure and corrosion of the underlying metal, since the pickled



Curve *A*—10% phosphoric acid spray
Curve *B*—Weathered and wire-brushed
Curve *C*—Control, pickled and wire-brushed

Fig. 7—Potential/time curves. Pretreated and painted surfaces, anti-corrosive paint *A*

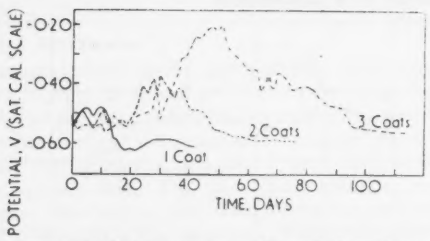


Fig. 8—Potential/time curves. Emeried surface ; one, two, and three coats of anti-corrosive paint *A*

surface remains at a more noble potential than either of the other two surfaces.

It is illuminating to compare these results with records made of the surface finish.* Chart records were obtained by means of the Talysurf instrument, the vertical magnifications employed varying from 400 to 10,000, to suit the degree of finish of each surface ; a horizontal magnification of × 50 was used throughout. Approximate figures for the magnitude of the surface indentations on each of the differently prepared surfaces are as follows :

Method of Surface Preparation	Depth, cm.	Width, cm.
Pickled	0·008	0·1
Emeried	0·0005	0·004
Ground	0·00003	0·002

The thickness of two coats of the paint system *A* was found to be of the order of 0·007 cm., that is, of the same order as the size of the irregularities on the pickled surfaces, thus making it very clear why breakdown occurs so much more quickly on this surface than on the emeried or ground surfaces, where the surface indentations are insignificant compared with the thickness of the paint film.

The influence of weathering or of spraying with a 10% solution of phosphoric acid prior to painting is illustrated in Fig. 7. The weathered specimens (curve *B*) were originally covered partly with adherent mill scale and partly with rust produced by weathering during storage in a marine atmosphere ; they were wire-brushed to remove loose rust and scale and were degreased before painting. The phosphated specimens (curve *A*) were first pickled (not wire-brushed) and then (with the faces vertical) sprayed with phosphoric acid solution. After allowing to dry overnight, when all the phosphoric acid had reacted with the steel, the specimens were bristle-brushed to remove the loose powdery product. This left the surface covered with an adherent grey coating of iron phosphate, which provided a good base for the paint. The curves in Fig. 7 show that a weathered and wire-brushed surface can give better results than a pickled and wire-brushed surface under the conditions of test, but it is probable that very variable results would be obtained with different specimens, owing to the variation in the condition of the weathered surface. The marked improvement in paint performance on a phosphated surface is shown by the greatly delayed period (about 40 days) before the maximum in curve *A*. These results agree with data obtained in rotor tests[10] (*loc. cit*, p. 21) of similarly treated specimens. Again it is significant that erroneous conclusions would be drawn from observations confined to the early stages of the potential/time curves.

* This work was kindly carried out by Mr. C. Timms, of the Metrology Division of the National Physical Laboratory.

Influence of Number of Coats of Paint

The delay in the onset of rusting, effected by the application of additional coats of paint, is clearly reflected in the electrode potential behaviour. The times taken to reach the maximum potential, and the maximum potentials reached, for various weights of paint *A* per unit area, were as follows :

Influence of Thickness of Paint on Electrode Potential Behaviour of Painted Steel

Coats of Paint	Wt. of Dry Paint, mg./sq. in.	Time to Reach Max. Potential, days	Max. Potential Reached, (sat. cal. scale), V.
Emeried Surface			
1	15·2	7	−0·480
1	15·6	14	−0·450
2	23·0	21	−0·480
2	28·5	30	−0·380
2	30·0	31	−0·320
3	43·5	48	−0·210
Ground Surface			
1	14·7	8	−0·475
2	26·4	26	−0·380
3	38·5	41	−0·230

The time required increases roughly linearly with the weight of paint per unit area ; the absolute value of the potential, though becoming more positive with increasing thickness of the paint (for any given paint), is nevertheless not a reliable criterion of the protective value, especially when comparing different paints (*see* Fig. 9). It is interesting to note that the relationship between the time taken to reach the maximum potential and the weight of paint per unit area, is here similar for the ground and the emeried surfaces, whereas previously (Fig. 6) the ground surface was slightly less reactive ; this difference may be due to the fact that a different (more resistant) batch of paint *A* (batch 2) was used here. Typical potential/time curves for one, two, and three coats of paint are given in Fig. 8. The difference in behaviour is clearly brought out.

Influence of the Type of Paint

The electrode potential technique has also been applied to the study of various paint systems. Potential/time curves are given in Fig. 9 for several anti-corrosive paints (described previously), applied as two-coat systems. The curves have been drawn on a somewhat compressed time scale, and hence the

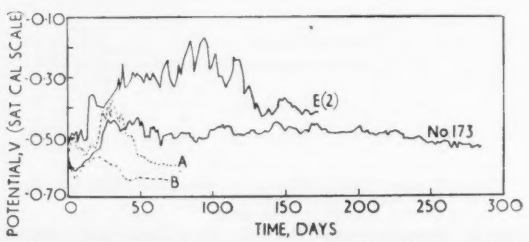


Fig. 9—Potential/time curves. Various paint systems

day-to-day fluctuations in potential appear accentuated. As mentioned previously, this fluctuation is greater the greater are the protective properties of the paint, and also, for each paint, it is least during the final period of declining potential. Paints *A* and *B* are of relatively poor quality, reaching maximum potentials after 30 and 20 days respectively. Paint *E*(2), although containing iron oxide as the chief pigment, nevertheless showed good protective properties (possibly because the pigment content was very high); the maximum potential was reached after about 90 days. The curve for paint No. 173 shows a true maximum at about 150–170 days. The high potential values obtained between 20 and 30 days do not constitute a true maximum. This period of somewhat unreliable potentials occurring early in the curve is characteristic of curves obtained from highly protective paints; it can be distinguished from the true maximum by the following criteria: (1) The potentials of duplicate specimens are often widely different, (2) the decline in the potential is not maintained, and (3) the specimen shows no rust spots at this stage.

This series of curves illustrates the fact (also referred to previously) that the actual value of the potential at the maximum is no guide to the protective value of the paint. A possible clue to the explanation of this variation in the value of the maximum potential has been revealed in later work, in which potential and alternating-current resistance measurements have been simultaneously obtained on immersed painted plates, in conditions similar to those used in this work. A roughly linear relationship was found to exist between the value of the maximum potential, and the alternating-current resistance at the time this maximum potential was reached; the higher the resistance, the more positive is the measured potential. This may be attributed to the greater iR drop through the paint film when the film has a higher resistance, but further work is required to establish the true explanation.

SUMMARY AND CONCLUSIONS

A description is given of an experimental technique that is suitable for periodical measurements of the electrode potential behaviour of painted steel immersed in a corroding liquid; artificial sea-water has been used in the present investigation. It has been shown that conclusions drawn from the shape of potential/time curves during the first few hours (or even days) may be quite misleading as a guide to the ultimate protective value of the paint. By continuing the measurements over much longer periods than have hitherto been used, the characteristic shape of the potential/time curve is obtained. Following an initial decline, the potential usually recovers and reaches a maximum value, which is succeeded by a gradual decline to more negative values. The period required to pass the maximum represents the useful life of the paint in the conditions studied. The shape of the potential/time curve is correlated with weight-loss/time and with area-rusted/time curves.

The technique has been used to investigate the influence of the following factors: the thickness of paint, the type of surface finish on steel, the method of pretreatment before painting, and the type of paint. It is concluded that changes in the electrode potential of painted steel immersed in artificial sea-water provide valuable information on the corrosion resistance of metal/paint systems in marine conditions.

Acknowledgments

The authors acknowledge the help received in the experimental work from Mr. A. W. Cooke and Mr. E. C. Seabrook. They gladly record their indebtedness to Dr. W. H. J. Vernon, O.B.E., for his interest and advice, and to Mr. V. A. Yardley and his staff for assistance in constructing apparatus and in preparing specimens. Dr. L. Hartshorn and Mr. E. Rushton (Electricity Division, National Physical Laboratory) have given valuable advice on experimental technique and on the interpretation of results. The authors' thanks are also due to Dr. I. G. Slater and Mr. L. Kenworthy, of the Admiralty Metallurgical Laboratory, Emsworth, for their interest in the work and for arranging the supply of steel and of paint samples. The investigation was carried out as part of the corrosion research programme of the Chemistry Research Board, and the paper is published by permission of the Director of the Chemical Research Laboratory, Department of Scientific and Industrial Research.

References

1. R. M. Burns and H. E. Haring: *Transactions of the Electrochemical Society*, 1936, vol. 69, p. 169.
2. A. Schweitzer: *Zeitschrift für Elektrochemie und angewandte physikalische Chemie*, 1936, vol. 42, p. 624.
3. A. Y. Pamfilov and G. N. Kiparisov: *Zhurnal Prikladnoy Khimii*, 1938, vol. 11, p. 1173.
4. L. Whitby: *The Research Association of British Paint, Colour and Varnish Manufacturers, Paint Research Station Technical Papers*, 1938, Jan., No. 96, p. 418; 1939, June, No. 125, p. 2.
5. H. E. Haring and R. B. Gibney: *Transactions of the Electrochemical Society*, 1939, vol. 76, p. 293.
6. V. O. Krenig and S. M. Ter-osipyan: *Novaya Tekhnologiya v Aviastroenii Bor'ba s Korroziei Metallov*, 1939, No. 4, p. 91; *Khimicheskii Referativnyi Zhurnal*, 1940, No. 3, p. 98. (Abstract in *American Chemical Abstracts*, 1942, vol. 36, No. 9, p. 2740.)
7. M. E. D. Jarrett: *Journal of the Oil and Colour Chemists' Association*, 1940, vol. 23, p. 40.
8. H. Zahn: *Paint, Oil, and Chemical Review*, 1946, vol. 109, p. 6.
9. F. Wormwell and D. M. Brasher: *Nature*, 1947, vol. 159, p. 678.
10. "Report of the Chemistry Research Board (D.S.I.R.) for the Period 1938–1946," p. 18. London, 1948; H.M. Stationery Office.
11. R. C. Bacon, J. J. Smith, and F. M. Rugg: *Industrial and Engineering Chemistry* (*Industrial Edition*), 1948, vol. 40, p. 161.
12. F. Wormwell, T. J. Nurse, and H. C. K. Ison: *Journal of The Iron and Steel Institute*, 1948, vol. 160, p. 247.
13. F. Fancutt and J. C. Hudson: *Journal of The Iron and Steel Institute*, 1946, No. II, p. 273P.
14. L. C. Bannister and U. R. Evans: *Journal of the Chemical Society*, 1930, p. 1368.
15. T. P. Hoar and U. R. Evans: *Journal of The Iron and Steel Institute*, 1932, No. II, p. 387.

Recent Steelplant Developments at the Appleby-Frodingham Steel Company

By A. Jackson, A.Met. (Sheffield), F.I.M.

SYNOPSIS

The paper commences with a brief mention of the development of tilting furnaces in the Appleby-Frodingham Steel Company's plant during the last 45 years, and proceeds to describe those incorporated in the new melting shop, completed about a year ago. It gives details of how increasing the width of the stockyard bay has affected its ability to serve the furnaces, followed by an outline of the mixer practice best suited to give maximum steel-furnace production with iron produced from Lincolnshire and Northamptonshire ores.

The dimensions of the most recently built furnaces are shown, with details of brickwork construction, regenerator plating, and gas-flue design from mixing to reversing valve. Some details of experiments on the stability of front linings, and a note of brickwork repair data are given.

The present operating methods used on these mixed blast-furnace and coke-oven gas fired furnaces are given briefly, with notes on operational control and an average charge. The plant is fully instrumented with certain automatic controls, and the methods of operation are described. Brief indications are given of methods used in operator training, and of welfare facilities. The pit side is described, as well as the method of drying and setting stoppers, etc.

The paper concludes with a note on recent operational developments, including auxiliary heating of gas checkers, heating up after repairs, a discussion on the effect of cutting off the gas supplied to the furnaces during reversal, and a summary of the effect of certain variables on production rates.

THE first European tilting furnace commenced steelmaking at the Frodingham Melting Shop in 1902. Further modernized furnaces were added, until the fourth came into operation in 1920. This shop was closed down on 2nd November, 1947, at 1.15 A.M., and is now dismantled. A new replace shop tapped the first cast of steel only about 12 hr. later, at 1.25 P.M., and was operated by the same men—in fact the early taps were made in the old ladles, as the new ones were not ready. This shop contained two 300-ton steel furnaces, and results have shown that in output it will entirely replace the dismantled Frodingham plant. The new shop carries the name, and, it is hoped, the traditions, of the old, but for present purposes of distinction it is called Frodingham (South) Melting Shop. Throughout this paper the name Frodingham Melting Shop will be used, as this is to be its final designation.

The Company's other steel plant, the Appleby Melting Shop, was designed in about 1918, but for various reasons did not become operative until 1927, when three of the original furnaces came into use. These were of 250 tons' capacity and, except for size and method of tilting, were essentially similar to the last furnace built at Frodingham, in 1920. The fourth Appleby furnace was started in 1930, being modified and raised to 300 tons' capacity, using straight-through valves and Friedrich blocks. The fifth furnace was built in 1937 and, until 1939, the fuel used in the shop was entirely producer gas. In this year the sixth steel furnace and second mixer were built and mixed-gas firing commenced, finally spreading to the whole shop within a year. The seventh steel furnace was designed in about 1942, but owing to war conditions it was not finally brought into operation, as a steelmaking unit, until 1946.

Manuscript received 3rd November, 1948.

Mr. Jackson is Works Manager (Steel) of the Appleby-Frodingham Steel Co.

This brief outline indicates little improvement in ideas of furnace design from, say, 1918 to 1930, when the fourth steel furnace was built, but since then each additional unit has been modified and the final results of all experiences are summarized in the new Frodingham shop. During these years expansion of plant has always been a possibility, and prospective modifications have been continually in mind and well considered by the time new construction has started.

Frodingham Melting Shop has not yet had a long life but it is believed that sufficient knowledge has been acquired to show the value of the changes made ; it is felt, therefore, that an early description of the plant would be particularly advantageous in view of prospective increases in steel production in this country in the near future. The description is not confined solely to what has been done but also mentions, whenever possible, other alternatives which were considered and discarded, this type of information being possibly of more value to plant designers than a straightforward description of the actual method used.

Before proceeding to further detail, reference must be made to the vast amount of work by a considerable number of people which is necessary to design, build, and operate a new melting shop. This paper goes even deeper, and recognition must be given to everyone who has been responsible for the operation and continued improvement of plant and process since the original furnace was designed. Finally, the initiators of the process, who backed their original venture, and those who have had the courage to capitalize continued improvement, must be remembered. The result has been seen in a record of continuity of employment for the operatives over many years that can hardly have been surpassed anywhere in the steel industry, and in steel plants which are second to none in efficiency. It is obvious, therefore, that the author has no special qualification to write

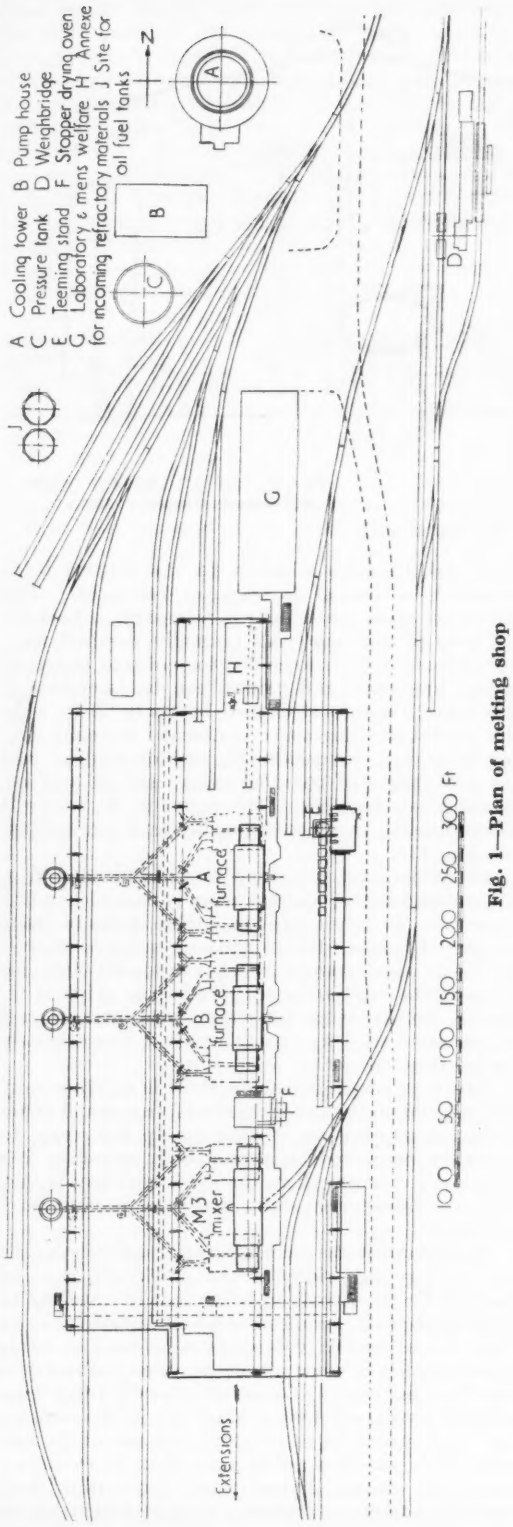


Fig. 1—Plan of melting shop

this paper, except possibly that of continued association over the years with the many changes involved, and it may be that being in charge of the melting shops is a specially favourable position for obtaining a general view of all of the work done by others for the benefit of that department. Thanks go to the staff in the producing departments, for, without their backing and extra work, much less time would have been available for obtaining a general view. Especially, thanks go to Mr. A. Robinson who, over the years, has continually encouraged and helped experimentation and advancement. Without him much less would have been accomplished.

The information which follows is confined essentially to work which has not already been published.

GENERAL

The Frodingham shop consists of two 300-ton capacity steel furnaces and one 600-ton active mixer. It is capable of extension, and, based on present experience at Appleby Melting Shop, it is proposed that the complete unit shall consist of six 300-ton steel furnaces and two 600-ton active mixers. Using 70–75% molten iron, with 0·8% silicon, 1·0% manganese, 1·45% phosphorus, and 0·075% sulphur, the annual ingot output will be 575,000–600,000 tons.

Figures 1 and 2 show the layout of the present plant. The water-circulation plant is at the north end of the shop. The softened water used throughout appears to offer considerable advantage over the normal supply, which is generally very hard and rapidly scales the water-cooling pipes. The return water main, in the melting shop itself, consists of an open-type trough fitted with loose covers, except where there are water inlets. This was installed after the experience of cleaning difficulties in the Appleby shop with a fully closed return water system.

STOCKYARD BAY

After considering and investigating most of the known methods of handling cold materials from wagon to steel furnace the method finally decided upon was the same as that used in the Appleby Melting Shop, and which has now been operating for approximately twenty-one years.

The main advantages of this method are :

(i) The amount and type of material available for charging is always visible to the melting-shop staff and this makes for simple and efficient control

(ii) No loco handling is required after the initial shunting of wagons into the stockyard bay

(iii) A maximum flexibility of supply to the steel furnaces is obtained, as any material already loaded on the stockyard floor can be ordered up to the charging bench at a moment's notice, whereas in plants in which the loading point is some distance from the melting shop, considerable re-organization of traffic may be necessary before modifications can be made.

The charging boxes used have a volume of approximately 25 cu. ft., and these are handled in the stockyard, on trays of five, by means of two double sets of hooks on the overhead crane. Loading of the boxes takes place by hand or magnet on the stockyard floor and the trays are then hoisted to stands at charging-stage level. This method of handling by trays is considered to be superior to either slinging the boxes by groups of chains, or lifting scrap by magnet to

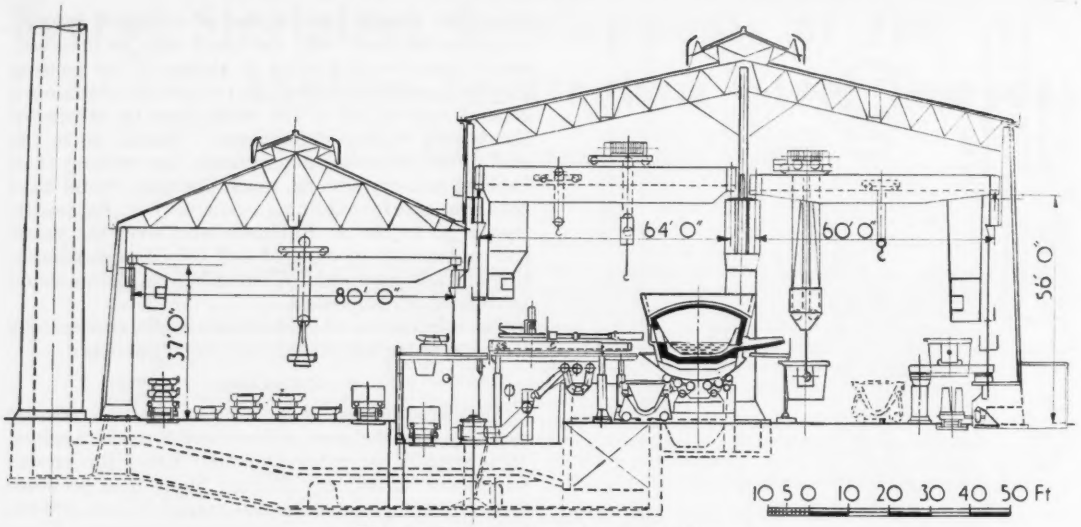


Fig. 2—Cross-section of melting shop

stage level and there loading the boxes. The former needs slingers, and the latter causes a considerable amount of cleaning up. Boxes loaded on the floor are much more accessible to the men ' squaring up ' than when they are on stands on the stage. With the tray method no slingers are necessary, the hooks being ' hung on ' by manipulation of the crane by the driver. The introduction of more positive methods has been considered, and tried, but they were either without appreciable mechanical success, or they prevented a magnet being suspended continuously between the lifting hooks, thus causing continual coupling and uncoupling of the magnet, or a need for two cranes, one for loading by means of a magnet, and another for lifting boxes.

The charging boxes could have been made larger for the new plant, but as they are used for direct loading of scrap from the plate mills, are common to the Appleby plant, and are cast in the melting shop itself from moulding boxes that are already available, it was decided that no appreciable advantage would result from increasing the box size just for the new melting shop ; if two types of box were in traffic together, they would be liable to become mixed, and then, as certain of the materials are charged ' by the box,' charging errors would be possible.

It is considered that the stockyard bay is of adequate size when it is equal in length to the melting shop. Its width has been increased to 80 ft., compared with 60 ft. in the existing Appleby shop. This increase is the major improvement that has been made on the charging side, and allows the assembly and stocking of loaded trays ready for charging.

The bay is served by two railroads, one on each side, and space is available in between for four rows of trays, the outer two for loading, and the middle two for stocking. Thus, opposite one furnace there is space for six trays on each side of the stockyard for loading, and between these can be set two rows of six, built up to three trays high, giving a total stocking capacity of 36 trays in the centre of the shop and 12 more adjacent to the wagons being unloaded—a total of 48 trays, or 240 boxes. This represents more space than is necessary to hold the 150 tons of cold materials normally required for a full charge ; in fact, some 200 tons of cold chargings (scrap, limestone, and oxides) can be assembled in this space. With a stockyard bay only 60 ft. wide, the central stocking space is absent ; therefore each tap necessitates a considerable rush on loading, with the probability of charging delays should adjacent furnaces tap together. The extra 20 ft. in width allows loading to proceed steadily and continuously (*see* Fig. 13).

All oxides and limestone are hand-loaded from wagons into boxes, whereas scrap is magnet handled, or arrives, already loaded in double decks of trays, on special bogies. Bloom and slab scrap is received in 25-ton steel wagons which are loaded with hot scrap in the mills from scrap-collecting skips at the shears. Breaker scrap (pit scrap, etc.) is also returned in the same steel wagons in which it was originally loaded from the pit.

Two men per shift, with a third in daytime only, load all cold materials for the steel furnaces and mixer, including supervision of squaring up the scrap, for a weekly ingot production frequently exceeding 5000 tons. All crane work in the stockyard bay is done by one driver per shift, and wagon damage is negligible.

Much thought was given before it was finally decided to increase the width of the stockyard bay, the main difficulty visualized being that of handling the high-speed 80-ft. overhead crane, as the driver would be at a considerable distance from his work at certain times, especially when placing trays on the stands on the charging bench. To obviate this difficulty it was at first considered that a fixed cab in the centre of the crane would be satisfactory, but one of the main objections was that, with more than two cranes in operation, certain drivers would be working backwards, an unsafe condition. Another suggestion was

that the cab should move with the crab. This raised possible electrical difficulties, but more important still, unless the height of the building was increased, there would be insufficient head room when the crane was working over the stands on the charging stage. Other difficulties arise from the possibility of the driver working backwards and the liability to damage the cab with swinging loads on the crane. After considerable discussion it was finally decided to retain the cab in the same position as in the Appleby Melting Shop, *i.e.*, fixed on the end of the crane farthest from the steel furnaces, the controls being situated so that the driver normally faces the charging bench. This was not done without fears of failure or of heavier wagon damage than had prevailed at Appleby with the shorter crane, but in view of the advantages that would accrue from the extra width of the building it was decided to try the method. Working results have proved that these fears were ill-founded.

The stockyard bay contains two cranes, each of 20 tons' capacity carrying a 65-in. Igranic magnet which is suspended by chains and is always in place, so that when trays are being lifted the magnet rests centrally on the top of the middle boxes and causes no inconvenience. The cranes themselves have a normal travelling speed of 400 ft./min.

Other means of handling materials in the stockyard have been tried or considered in the past. Grabs have been used to replace magnets, but are not very satisfactory, as the grab has to be removed when trays are to be lifted, and additional cranes would be necessary.

The possibility of using bunkers for many of the materials in the stockyard was considered, but it appeared obvious that it would not be possible to produce an alternative system having the efficient simplicity of that in use at present. Furthermore, no possible saving in manpower could result ; in fact, it is probable that more labour would be required, though possibly of a lower grade.

The stockyard bay should not be used as a dumping ground for 'dead' stock, as this wastes valuable space which could be used to speed up charging. Materials stocked in piles on the floor are seldom used, except for emergency purposes, and then it is probable that they have to be carried by crane from end to end of the building. The piles also make the building untidy, and a stock of one kind of material is liable to serve as a dumping ground, or accumulate spillage, until it is difficult to tell from the upper surface of the pile what the stock consists of. Probably the only material worth stocking is heavy scrap, which serves a useful purpose in an emergency, and probably is necessary to carry the shop over the weekend, when the normal flow from the mills is interrupted.

One difficulty in the Appleby shop was that of maintaining a safety fence on the edge of the charging bench, where there is normally a direct drop of some 20 ft. to the stockyard floor. Various methods were tried, but finally, light steel supports, slotted into sockets let into the floor and connected by chains, were used. These were frequently displaced by the cranes, but in theory could be easily put back into place without appreciable cost. Generally they were displaced, and some nine years ago it was decided to build a fence so firm and strong that the crane would be unable to damage it appreciably. The finished steel structure, shown in Figs. 14 and 15, is relatively costly, but no repairs have been made in nine years, and there appears to be no reason why any should be required in the next nine. This is an adequate solution of a difficult problem, and has therefore been adopted as standard practice in every place possible.

The stands, on which the boxes are placed on the edge of the charging stage, were difficult to clean, but this difficulty has been overcome by welding sloping plates in triangular formation between the ends of the stands, so that any material spilled slides down the plates and has not to be raked laboriously from underneath the boxes. Cleaning round the stands in the new melting shop is part of the duty of one man per shift, who also is responsible for cleaning and sweeping the valve arch, the teeming stand, and the casting bay. The box stands are illustrated in Fig. 15.

MIXER PRACTICE

Iron Transfer

Molten iron is transferred from the blast-furnace to the steel plant in 70-ton semi-closed ladles, shown in Figs. 16 and 17. Originally, 30-ton open-top ladles were used, but these were discarded, as the ladle-lining costs were double those of the semi-closed type ; in addition, the loss of iron as ladle skull was also much higher, being 2·15% compared with 0·35%.

The addition of soda ash at the blast-furnaces for desulphurizing has been considered, but this cannot be accomplished satisfactorily in the semi-closed type of ladle, as the sulphur-bearing slag cannot be removed properly. Open-top ladles are necessary, and the cost of increased ladle skull has to be added to that of the soda ash used, as well as the bad effect on the furnace refractories of soda-bearing slag, some of which will always find its way into the mixer no matter how well the ladles are skimmed.

Mixer Design

Originally mixers of relatively large capacity were designed, but they were provided with gas and air regenerators smaller than those of current open-hearth furnaces. Firing was by blast-furnace gas of 104 to 109 B.Th.U./cu. ft. The mixers formed storage reservoirs of considerable size, and served their function of mixing metal from the various blast-furnaces and retaining it at a reasonable temperature until it was withdrawn for use in the open-hearth furnaces.

If the charged iron contained from 1 to 1·5% of manganese, upwards of 40% of the sulphur would be removed by flotation as manganese sulphide. Flame oxidation was followed by the oxidation of some of the silicon, and the resulting silica was prevented from eroding the bath unduly by the addition of limestone or local lime-bearing iron ore. In the aggregate, therefore, up to 30% of the silicon content of the iron may be removed also, as well as probably 15% of the manganese content ; practically no phosphorus or carbon will be removed.

In time, following changes in operating methods, the benefits of lower silicon content on the production

rates of open-hearth furnaces became increasingly apparent. This led, through various modifications in design, to improvements in the heat input to the baths of existing mixers, and finally to the modern type build in 1938, which is virtually the same as a 300/350-ton steel furnace, but which is equipped with a bath capable of carrying a maximum weight of 550–600 tons of molten iron, though the average loading is about 350–400 tons. (*See* Figs. 3, 4, 5, and 6.)

The bath is 49 ft. 6 in. × 18 ft. 3 in. × 6 ft. All of the remaining dimensions shown for the *A* and *B* furnaces in Frodingham (South) Melting Shop apply to the mixer, except that :

(i) The roof height of the mixer from sill level is 3 in. less, and the span is 21 ft. 8 in. compared with 20 ft. 2 in. for the steel furnaces

(ii) The gas regenerators are 1 ft. 4 in., and the air regenerators 1 ft. 1 in. less in height than those in *A* and *B* furnaces.

Ports, uptakes, valves, and flues are the same as in the steel furnaces, and the regenerators are a little less ; therefore the mixer can be maintained at steel-furnace temperatures. The mixer, as a fully active unit, takes advantage of this fact and plays a most important part in the total refining process.

Instrumentation and Control

The instrumentation and control methods are exactly the same as those used for the steel furnaces. The furnace temperature is a little below that of a steel furnace at tapping, but is near the general average, as will be gathered from the amount of materials melted and the refining that takes place.

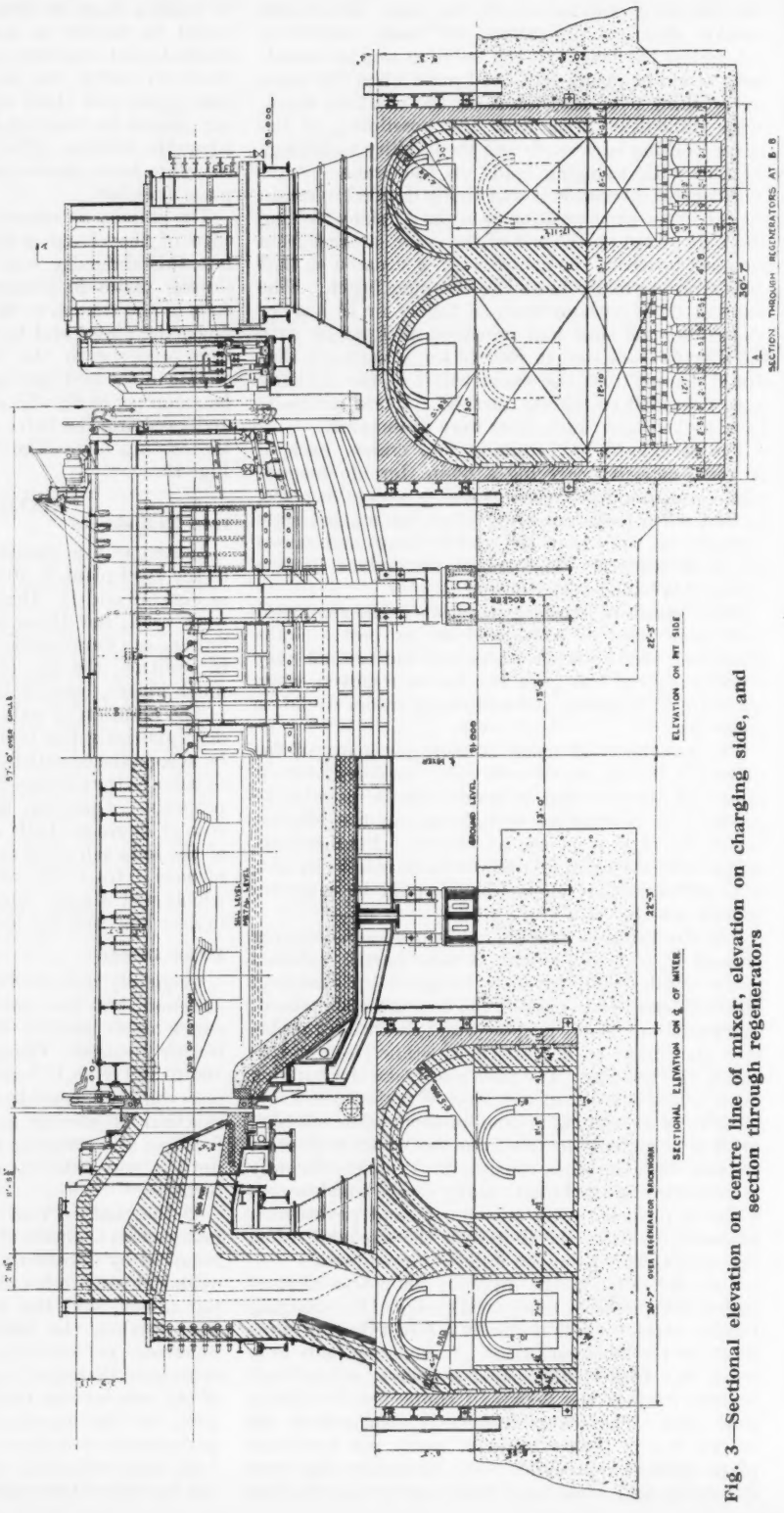


Fig. 3—Sectional elevation on centre line of mixer, elevation on charging side, and section through regenerators

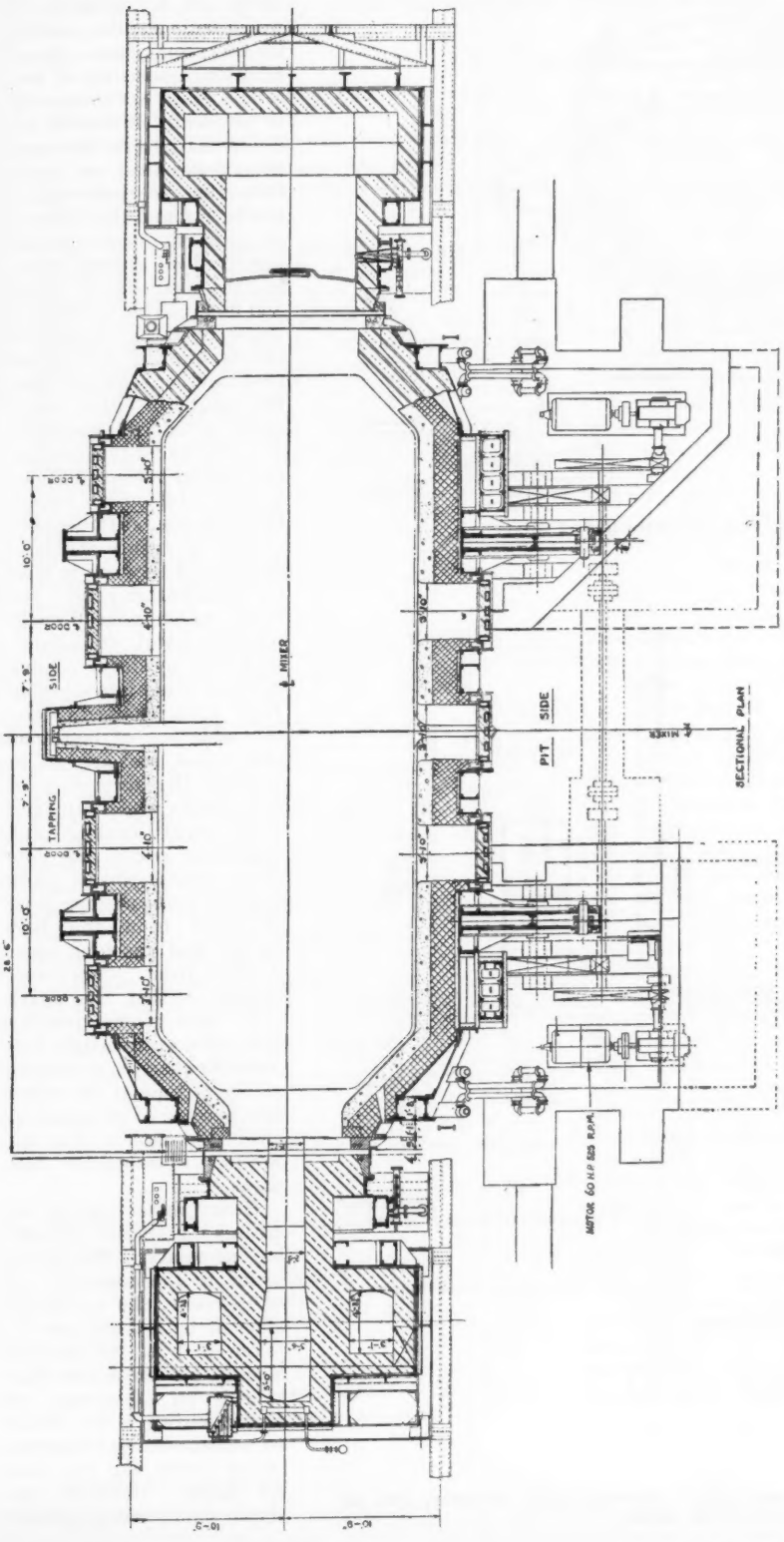


Fig. 4—Sectional plan of mixer

Operation

Early increases in mixer feeding were devoted to the production of a relatively uniform silicon in the molten metal supplied to the open-hearth furnaces. Thus, the rate of addition of oxides and fluxes was at a maximum only when the incoming iron was most siliceous, and was at a minimum when the silicon content approached that of the predetermined outgoing metal. Two important disadvantages of this method were :

(i) The mixer never worked to its full refining capacity, except during the short periods when the incoming silicon was at its maximum. Normally it would work at about 55% capacity.

(ii) Even if relatively constant silicon was obtained the temperature of the outgoing metal was liable to fluctuate considerably, being lowest when the mixer was being charged with the maximum quantity of refining addition.

A number of years ago, following considerable chemical and statistical work, a method of slag control in the open-hearth furnaces was introduced,* and has been worked with advantage ever since. This method, with modified charging arrangements, allowed adequate compensation in the open-hearth furnaces for variations in silicon content in the iron supplied from the mixer. Since then, mixer refining has been speeded to the utmost by melting the refining additions continuously and as rapidly as possible, so that the molten iron produced is only slightly

* A. Jackson, *Journal of The Iron and Steel Institute*, 1944, No. I, pp. 49P–66P.

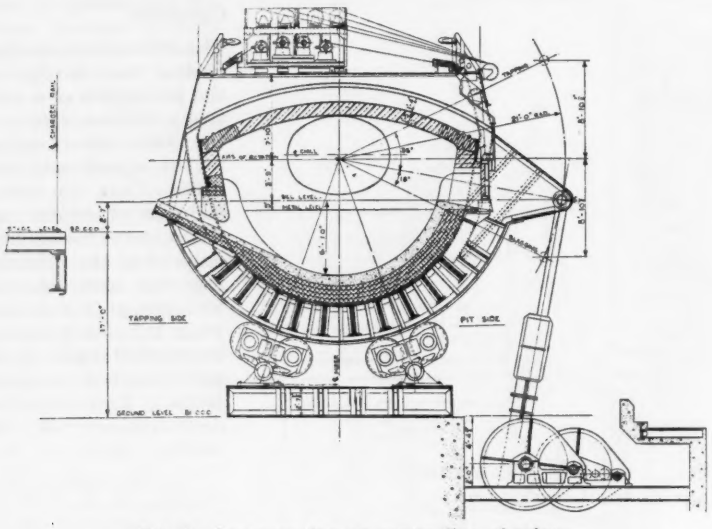


Fig. 5—Cross-section on centre-line of mixer

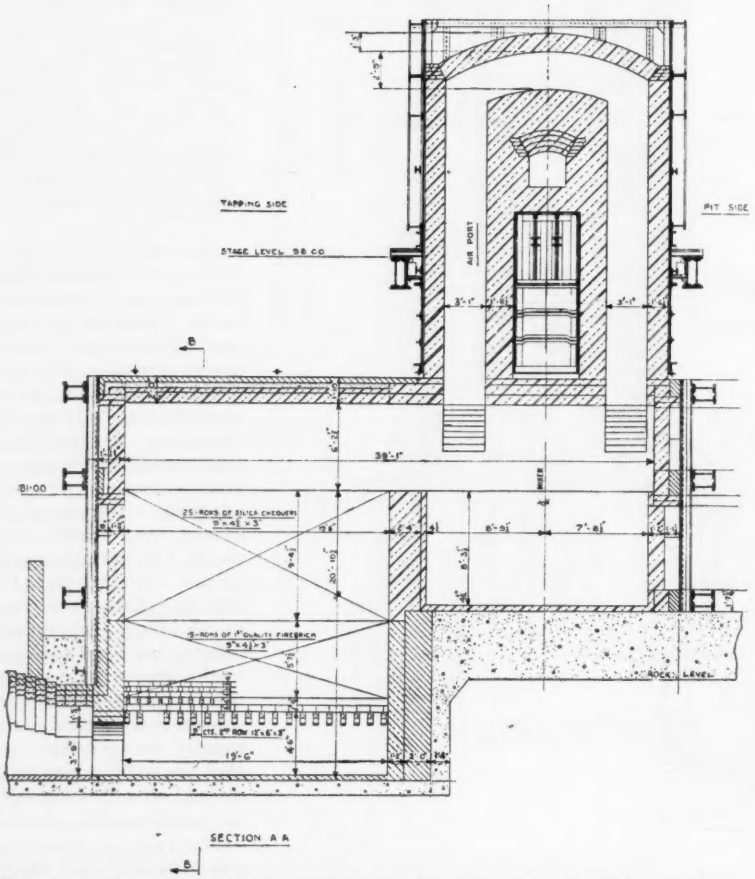


Fig. 6—Section through air regenerator chamber, slag chamber, and air uptakes on mixer

above the temperature at which ladle skulling, during transfer, commences. Scrap additions, consisting of materials which are chemically or physically unsuitable for direct charging to the open-hearth furnaces, are made from time to time, and it has been found that there is an optimum quantity which can be added without reducing the quantity of oxides and fluxes. This means that under operating conditions the total weight of scrap and feed together is greater than the weight of either which could be added separately. The reasons for this are that the melting of feed additions at the metal surface cannot take place sufficiently rapidly to reduce the temperature of the bath to near its solidification point; but scrap, which sinks directly into the metal, will accomplish this by direct cooling before it passes into solution. Light scrap, charged among the additions of limestone and oxides, also appears to prevent the formation of large lumps which can arise with rapid feeding and materially reduce the rate of operation—this is probably the point needing most attention from the first melter and machine men. A final point, often overlooked, is that the mixer must have general priority over the open-hearth furnaces for charging materials, as loss of time at the mixer can, because of its capacity, affect the molten iron for several open-hearth furnaces.

Heavy mixer feeding increases the amount of fettling necessary. Therefore, owing to the angle of rest of dolomite, the maximum efficient bath depth can be taken as 4 ft. In practice slightly greater depth than this is an advantage, as heavy feeding is also liable to cause heavy foaming, which forces slag out from all doors. However, the depth should not be greater

than 5 ft., and 4 ft. 6 in. should be considered normal. Further reasons for favouring reduced depth are :

(i) The furnace can be slagged more easily and more frequently

(ii) The metal can be heated more satisfactorily

(iii) More opportunities arise when the metal level is sufficiently low to allow fettling to commence from the base of the banks.

The chemical effects of the shallow, heavily fed mixer differ markedly from those of the deep reservoir type mentioned previously, in that up to 75% of the silicon and 45% of the manganese will be eliminated ; but sulphur removal will be low, while some phosphorus and carbon will be removed by oxidation, and the remainder by scrap dilution. The reduction of silicon (and phosphorus) reduces the slag volume in the open-hearth furnace. In consequence, the residual manganese in the bath does not suffer appreciably, because of the relatively high loss in the mixer. For normal specification steels little trouble arises from sulphur, provided the amount in the iron supplied by the blast-furnaces does not average above 0·075%, though for higher-quality steels an extra slag may be needed.

Heavy mixer feeding would be unnecessary in plants using high percentages of scrap, and under these conditions the large-capacity relatively inactive mixer, removing little silicon but more sulphur, is obviously most advantageous, and the same type could also be used for a hot-metal plant using low-silicon, but higher-sulphur, manganese-bearing iron. The method employed in the practice at Appleby-Frodingham gives most favourable results, but mixer design must be suited to the type of practice to be used, and cannot be changed from day to day. The mixers shown have a designed depth of over 6 ft., and this could be achieved, if necessary, during a general repair. In present-day practice the bottom depth is within the limits previously discussed.

Average operational details of the first twelve months' working are given below :

Iron in	C	3·5%	**Iron out**	C	2·85%
	Si	1·06%		Si	0·24%
	S	0·085%		S	0·073%
	P	1·53%		P	1·15%
	Mn	0·98%		Mn	0·48%

Slag analysis	SiO_2	27·8%		Fe	6·8%
	CaO	39·8%		P	2·4%
	Mn	6·2%		S	0·19%

Slag made 1·77 cwt./ton of iron

Production 3500 tons/week

Chargings, cwt./ton	Oxides	1·03
	Scrap	2·21
	Limestone	1·08

Dolomite 0·14 cwt./ton

Fuel, cu. ft./hr.	Blast-furnace gas	235,000
	Coke-oven gas	51,400

2,600,000 B.Th.U./ton of mixer metal

Checker temperature,° C.	Air	1030–1150
	Gas	1018–1190

Chimney temperature 389° C.

Draught (chimney flue) 0·95 in. W.G.

Elements Removed

An examination of figures over a number of years shows that : (i) If, in the iron charged, the manganese content is between 0·8 and 1·5%, the amount removed is almost constant at 40% of that charged, and this amount appears to remain relatively unchanged, even when the rate of silicon removal is doubled ; (ii) the rate of sulphur removal increases with an increase in the manganese content of the iron charged, but decreases with increasing rates of silicon removal if the manganese in the iron charged remains constant ; (iii) the rate of silicon removal depends essentially upon the rate at which the mixer works through the added oxides and fluxes.

Mixer Slags

Examination of a considerable number of figures indicates that : (i) The combined silica and phosphoric acid content of the slag is substantially constant between 32 and 35% ; (ii) wide variations in the lime content occur, but the relative constancy of the total of lime, magnesia, and manganese oxide indicates that the percentages of manganese oxide and lime are approximately interchangeable ; (iii) the sulphur content of the slag increases with increasing manganese oxide content, and decreases with increasing lime content ; from this it is concluded that high manganese oxide in the slag, resulting from high manganese in the iron, gives a slag carrying much more sulphur than a higher-lime slag which appears to result automatically from the use of a lower-manganese iron.

Estimation of the Operational Efficiency of the Mixer

To give an immediate and obvious indication of the efficiency of the mixer two daily figures are used. Firstly, the slag is estimated for the iron as a control each time any is removed. Secondly, and more difficult to obtain, is a figure for the rate of refining.

If a mixer is working to give a constant outgoing-iron analysis, frequent samples estimated for silicon will give the required information. If, however, the furnace is being used to give maximum silicon elimination, then, in addition to the analysis, the weight of molten iron taken out must also be available. Although the mixer is being fed so rapidly that the outgoing temperature is almost down to skulling point in the ladles, it is found in practice, that the quantity of oxidizing additions which can be melted increases somewhat with increasing throughput of iron. This is probably caused partly by the increased amount of agitation of the metal and slag during charging and discharging, as well as the presence of a greater amount of silicon to be removed. Therefore, the furnace is less likely to reach the point when the removal of the last few points of silicon from the metal becomes increasingly difficult.

Under normal operating conditions the effect of feeding is expressed in tons of silicon removed in unit time. The following data can be achieved without undue damage to the mixer hearth and linings, and they are used, therefore, as basic standards :

Weekly Output, tons	Silicon Removed	
	Tons	%
6000	30	0·50
5000	28	0·56
4000	26	0·65
3000	24	0·80

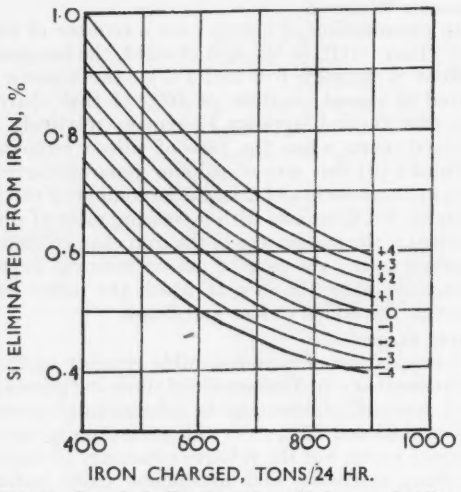


Fig. 7—Graph indicating the efficiency of silicon removal in mixer

From these figures a daily rated curve is drawn (*see* Fig. 7) and is marked zero. Parallel to, and on either side of this, are curves, each of which indicates a 5% variation above or below standard—thus a single figure can show the efficiency of daily silicon elimination.

The foregoing data are obviously applicable, in general, to one type of mixer practice, but Fig. 8 is plotted from them, and gives a reasonable approximation of the possibilities of the mixer with variations in throughput and composition of the iron charged. The data in Table I are derived from Fig. 8, and give some examples of the ratio of possible throughput to ingoing silicon analysis required to give a constant outgoing metal.

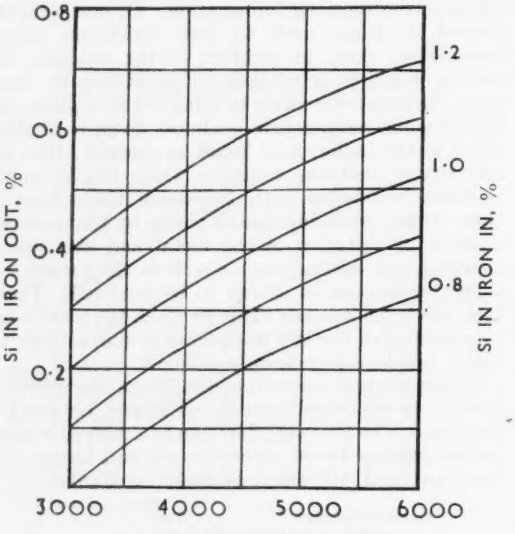


Fig. 8—Ratio of silicon in iron into and out of mixer to weekly production rate

These data indicate that, if the silicon content of the iron as charged increases from 0·8% to 1·1%, two mixers will be required instead of one, if the ougoing silicon is to remain at an average of 0·3%.

Economic Advantages of the Mixer

It has been suggested from time to time that a mixer is uneconomic, and that greater ingot production would be achieved if the mixer was replaced by a steel furnace and all worked on direct metal.

Assuming a blast-furnace iron with 1·0% of silicon, and 300-ton tilting furnaces fired with mixed coke-oven and blast-furnace gas (the least favourable case, as producer-gas-fired furnaces give a slightly higher production), the data in Table II furnish an estimation of the increase in production which can result from use of the mixer.

The data in Table II show that a gain in ingot production would occur with two and three furnaces if the mixer was replaced by a steel furnace, but with four furnaces and one mixer, production is the same as with five steel furnaces working direct metal.

If the active mixer was abolished, an inactive tank mixer would definitely be necessary, especially with the variable iron and the considerable differences between the tapping capacity of the blast and the steel furnaces. The materials consumed would also increase in quantity, because of differences in fuel, dolomite, and refractory costs between mixer and steel furnace. Lime consumption and iron loss would increase by the difference between the relatively acid slag from the mixer and that from the open-hearth

Table I

EFFECT OF SILICON CHARGED ON MIXER THROUGHPUT

Silicon Charged, %	Mixer Throughput, tons/week	
	Outgoing Silicon, 0·2%	Outgoing Silicon, 0·3%
1·2	...	2500
1·1	2500	3000
1·0	3000	3650
0·9	3650	4500
0·8	4500	6000

Table II

EFFECT OF MIXER ON STEEL FURNACE PRODUCTION

	2 Steel Furnaces	3 Steel Furnaces	4 Steel Furnaces
Si from mixer, %	0·25	0·405	0·50
Mixer output, tons/week	3300	4650	6000
Steel furnaces, tons/hr.	13·1	12·4	11·9
Steel furnaces, tons/week	2201	2080	1999
Total ingots, tons/week	4402	6240	7996
Production without mixer, tons/week	3200	4800	6400
Gains with mixer, tons/week	1202	1440	1596

furnace. The refractory cost for brickwork in the mixer per ton of iron is only 11% of that for the steel furnaces per ton of ingots.

There is no doubt that a mixer is economically advantageous when used with three steel furnaces, but the advantages with two steel furnaces would be slight.

STEEL FURNACES

Drawings of the steel furnaces are shown in Figs. 9–12, and the leading dimensions are summarized here :

Hearth	Length 45 ft. Width 15 ft. Area (90% of $l \times w$) 608 sq. ft.
Roof	Height of centre above sill level 8 ft. ½ in. Span (inside linings) 20 ft. 2 in. Rise 2 ft. 6 in. Thickness (main roof) 1 ft. 3 in. Thickness (ends) 1 ft.
Gas Ports	Height 2 ft. Width 2 ft. 7 in. Slope 1½ in./ft. Length (from inside uptake wall) 16 ft. 6 in.
Air Ports	Height 2 ft. 5 in. Width 9 ft. 2 in. Slope 9 in./ft. Length (from inside uptake wall) 13 ft. 6 in.
Uptakes	Gas : Length 5 ft. Width 3 ft. 6 in. Area 17·5 sq. ft. Air : Length 4 ft. 3 in. Width 3 ft. 1 in. Area 13·2 sq. ft. Area of both uptakes 26·4 sq. ft.
Checkers	Gas : Length 19 ft. 6 in. Width 8 ft. 6 in. Total height to top of arch 23 ft. 6 in. Air : Length 19 ft. 6 in. Width 12 ft. 10 in. Total height to top of arch 23 ft. 6 in. Height of checkered brickwork 16 ft. 9 in.
Slag Pockets	Gas : Length 16 ft. 6 in. Width 7 ft. 1 in. Height to the top of arch 14 ft. 6 in. Air : Length 16 ft. 6 in. Width 11 ft. 6 in. Height 14 ft. 6 in.
Flues	Gas : Width 4 ft. Height to the top of arch 6 ft. Area 22·3 sq. ft. Air : Width 4 ft. Height to the top of arch 8 ft. Area 30·3 sq. ft. Chimney : Width 4 ft. Height 8 ft. Area 30·3 sq. ft.
Valves	Gas : 14 sq. ft. (minimum area for waste gases) Air : 22 sq. ft. (minimum area for waste gases)
Chimney	Inside dia. at base 9 ft. 2 in. ,, ,, ,, top 7 ft. Height 170 ft.

These dimensions represent the present stage in the evolution of the Appleby-Frodingham furnaces. The following variations from previous practice were made.

The roof span was increased from 19 ft. 2 in. to enable increased slope to be used on the front lining, and the roof rise was increased by 3 in.

The gas-port length on the original Friedrich block-type furnace was 20 ft. 6 in., and this was increased to 21 ft. in two later furnaces. It was very difficult to keep the port clean and maintain the shape properly at the furnace end because of the long tools necessary, and because they bent so quickly in the heat. The port was shortened in the last three furnaces to 16 ft. 6 in. as shown in the drawing. This length is quite satisfactory, and, since maintenance is easier, good gas direction can be obtained continuously. From these trials it is believed that the full length from the inside of the back stop to the port nose need not exceed 15 ft. It should be remembered that this length includes the width of the uptake (*see* Figs. 19 and 20).

In the original furnace design for this type of block the three uptakes were enclosed separately in steel casings. Now they are built together in one block, and are steel-cased on the outside only. No trouble has arisen from mixing between gas and air uptakes, and the original scheme has been operating for over four years. The gas uptakes have been increased from 15·1 sq. ft. to 17·5 sq. ft., and the air uptakes from 11·6 sq. ft. to 13·2 sq. ft. The size of the uptakes was not increased because of difficulties encountered with the smaller sizes, but because the saving in space effected when the uptakes were put in one binding permitted the increase without major structural alterations. It is considered that these areas are adequate for the furnaces and this belief is borne out by the fact that the one furnace with larger uptakes in the Appleby shop, working under otherwise identical conditions, has not shown any improvement over the other furnaces.

The length of the checkers has been reduced from 20 ft. 6 in. to 19 ft. 6 in., and the width increased by 5 in. In the first three furnaces built in the Appleby shop the total height of the checker chambers to the crown of the arch was 18 ft. 9 in. This was increased to 22 ft. 3 in. for the first two 300-ton furnaces built, and to 25 ft. 3 in. for the second two 300-ton furnaces. The checker chambers of the furnaces of the new plant were reduced to 23 ft. 6 in., and this height is quite satisfactory ; in fact it could be reduced to 22 ft. without difficulty, and no disadvantage would arise in mixed-gas furnaces. With cold gas and air, the flue temperatures stay well down, and very deep checkers are liable to cause considerable trouble owing to kicking in the flues during reversal, these flues being normally relatively cold. To obviate this difficulty a 4-in. dia. pipe passes from ground level into the stack flue. Within this pipe are 1½-in. dia. and ½-in. dia. pipes carrying coke-oven gas, the small one being always alight. Before the furnace can be reversed the 1½-in. gas pipe must be turned on, the gas ignites from the pilot light and burns in the flue, with air passing down the outer 4-in. pipe. In this way the reversal gases are ignited and kicking is prevented. As soon as reversing is complete the main gas supply is turned off, leaving only the pilot light. The pilot light was unreliable when used alone for ignition, as, during reversal, it was often put out by

the gas from the checkers. Checker-filling heights of 15 ft. 6 in. would be adequate for these furnaces and would still enable stack temperatures to be maintained well under an average of 500° C.

The height of the slag-pocket remained the same, the width was increased by about 5 in., and the length was increased by 1 ft. 4 in. to bring the inside downtake well clear of the bridge wall, thus ensuring that the gaseous flow was not materially influenced by the proximity of the wall.

These alterations are the main differences between the new plant and the Appleby Melting Shop. The changes have in each case proved advantageous, either by improved efficiency or by reduced costs.

Brickwork of Regenerator Chambers

Originally the inner walls of the regenerator chambers were lined with firebrick to the level of the first eight courses of checker work, and the remainder of the chamber, including the roof and slag pockets, was silica brick. Fluxing between the upper courses of the inner walls and the checker bricks gave trouble, and the wall was damaged fairly considerably at each major repair. A false wall, consisting of a layer of old bricks, 3 in. thick, was built up with the checkers to form a loose lining which takes all fluxing wear, but which is easily removed when the checkers are taken out, as it does not stick to the main chamber wall.

After the introduction of this method it was found that the walls failed lower down, and behind the false wall. This was apparently caused by the silica bricks passing through a low-temperature change point too frequently, so that in the aggregate, failure was merely

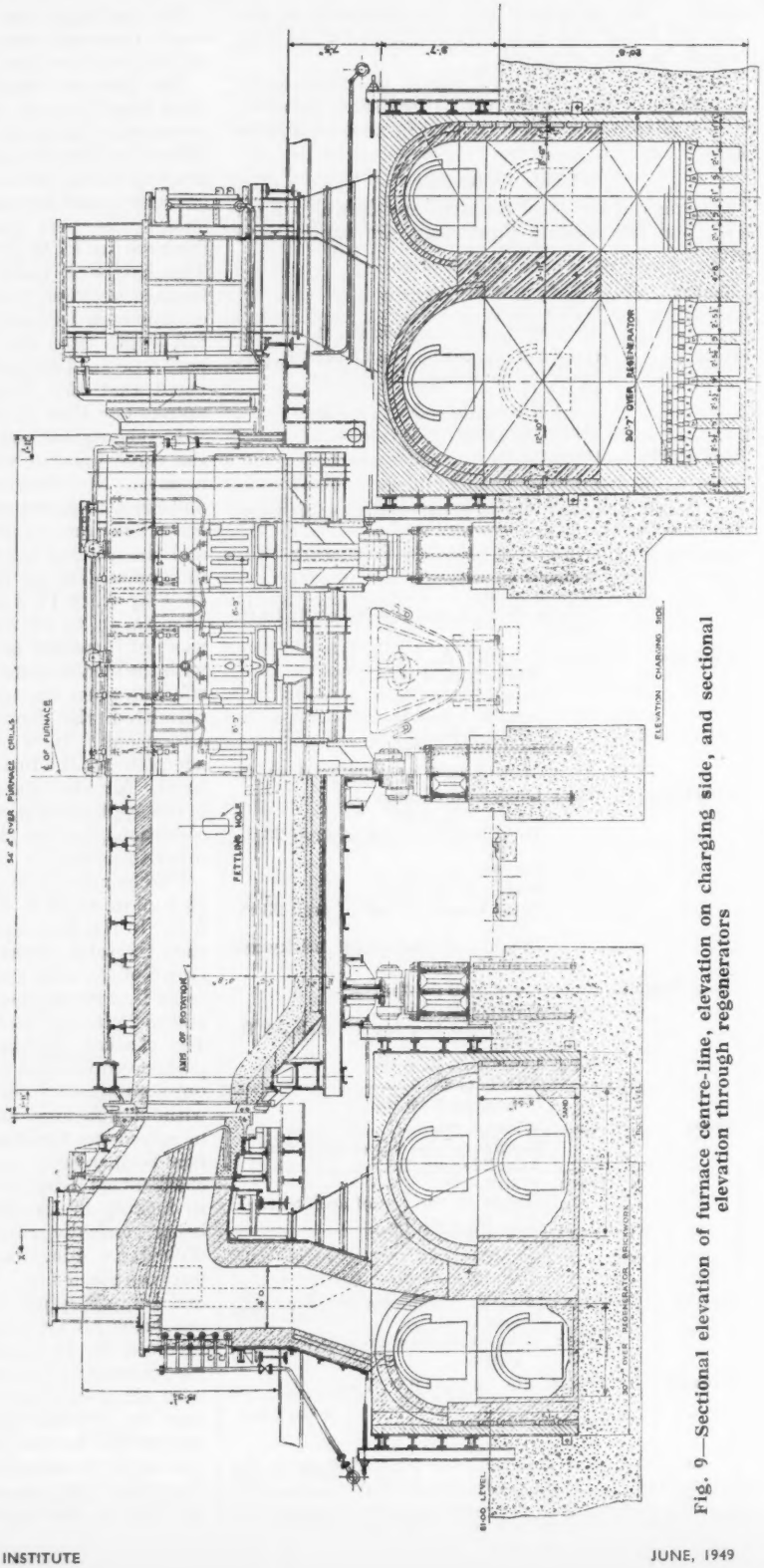


Fig. 9—Sectional elevation of furnace centre-line, elevation on charging side, and sectional elevation through regenerators

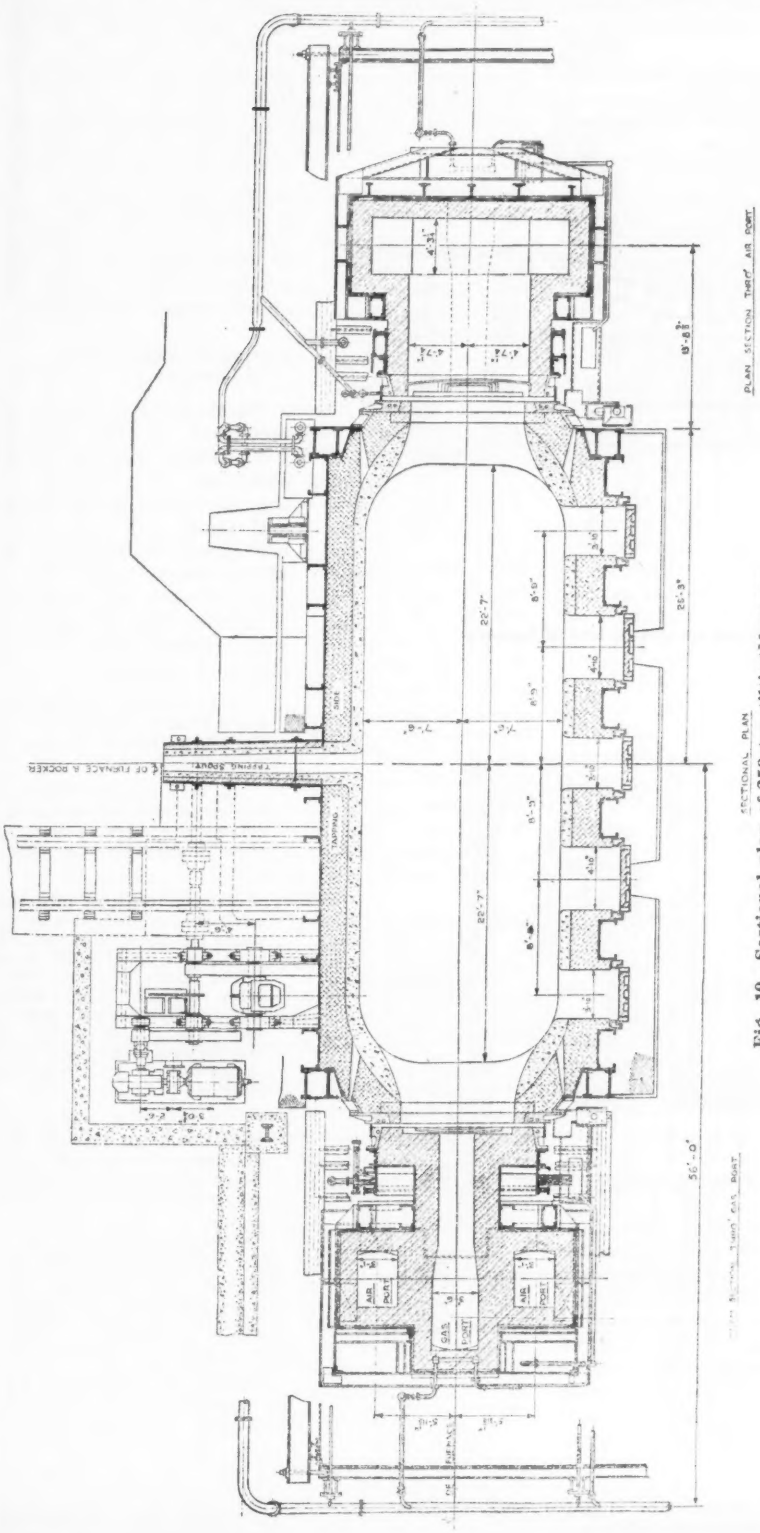


Fig. 10—Sectional plan of 350-ton tilting furnace

transferred from the upper parts of the chamber to some point at, or a little below, valve pit level. The chambers are now built of firebrick for about two-thirds of the total height and have proved completely satisfactory. The regenerator chambers are insulated above ground level, and the gas uptakes on three sides ; the fourth (outer side) wears away rapidly and must be partly replaced after each run, in spite of the back stop of the gas port being water cooled.

The bricks normally used in the gas checker are 9 in. × 4½ in. × 3 in., set to give 6 in. × 6 in., straight flues. The air checker uses 9 in. × 4½ in. × 3 in./2½ in. bricks set at 9-in. centres as a side arch, but staggered in both directions as described previously. Approximately four years ago a trial was made using both gas and air checkers built so that they consisted of a series of 3-in. solid walls set 6 in. apart (*i.e.*, at 9-in. centres) and at right-angles to the long axis of the chamber. These walls were spaced by cross-bricks in each course, set at 18-in. centres, and staggered vertically in adjacent courses to strengthen aud space the walls. In the first trial the checkers lasted over two years without replacement, and were cleaned each time the furnace had a major repair. The second trial had the top half of the gas checkers replaced after about 85 working weeks, the remainder being cleaned to remove dust when the furnace was off. This design requires more bricks than the normal type, but appears to need less bricks per ton of ingots, and, of course, reduces repair time because of its longer life.

Another trial, commenced about six months

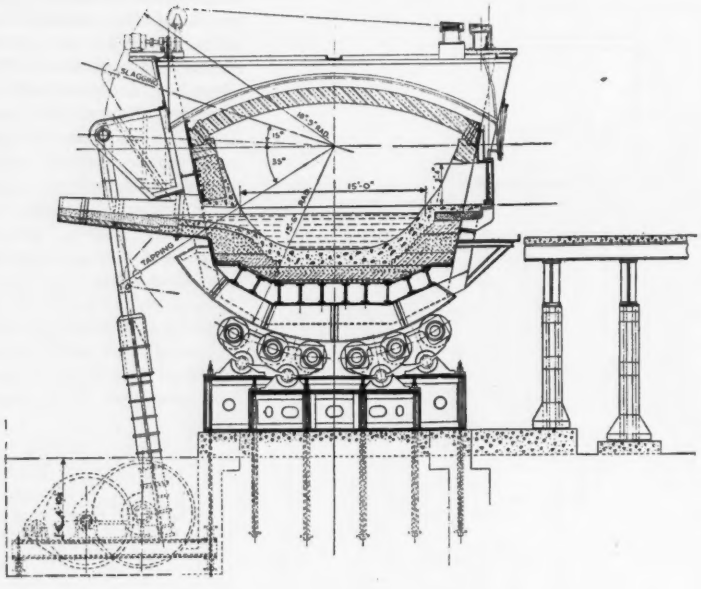


Fig. 11—Cross-section on centre-line of furnace

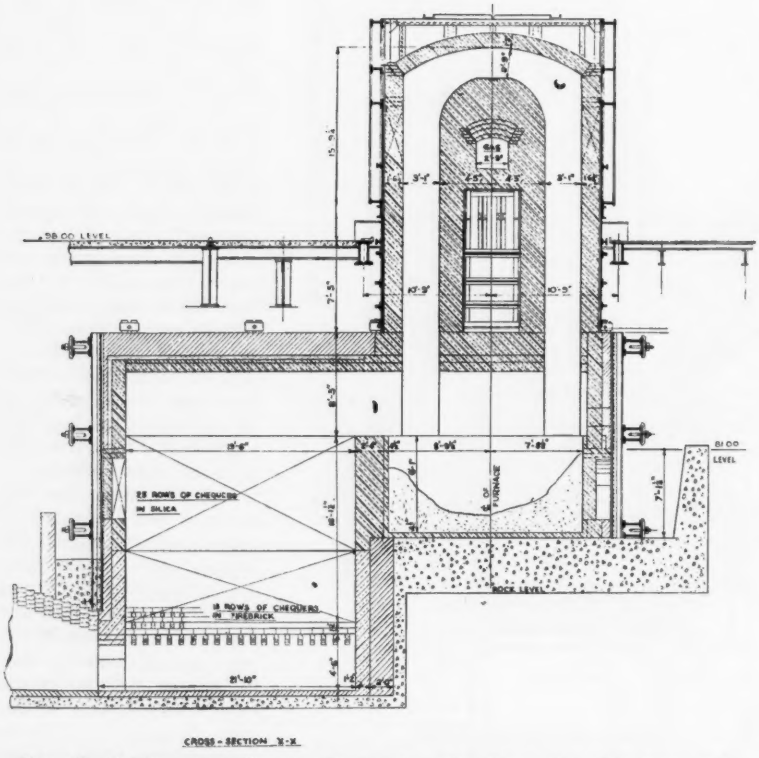


Fig. 12—Section through air regenerator chamber, slag chamber, and air uptakes on furnace

ago, uses special bricks, shaped so that they give checkers consisting of vertical solid flues 6 in. square. This method is used for about two-thirds of the checker height, finishing with bricks in the normal manner. It is expected that the solid flues will last for a number of years and only the top portion, which is readily accessible, needs replacement.

Plating of Regenerator Chambers

When mixed gas was first used in the Appleby shop in 1939, acting on advice available, all the regenerator chambers were pulled down and rebuilt with each chamber plated separately, and with a cavity about 18 in. wide between gas and air chambers. This arrangement was unsatisfactory for the following reasons :

(i) Gas leaked behind the outer plating and escaped at the edges, which, of course, were mainly at the top

(ii) Gas escaped between the chambers and burnt inside in inaccessible positions, thereby damaging the structure

(iii) Gas escaped into the cavity between the slag holes, burnt out the steel structural work, and continually gave minor kicks a short time after reversal. These kicks were not particularly heavy, but gave a puff of gas at the furnace doors and were dangerous to men working nearby

(iv) Chamber widths had to be reduced because the thickness of two walls must be greater than that of the common wall used formerly.

Considerable discussion took place when the new plant was planned, and designers were most reluctant to give up this method of plating. Finally the adjoining gas and air checkers were designed with a common centre wall, and the outer walls had no steel plate above ground level, so that all the brickwork was accessible and could be made up where the

leakage was actually taking place. Pointing up is necessary after each furnace repair, but generally the method is definitely better in maintaining a gas-free atmosphere in the melting shop, and the design will be continued in future furnaces. As the Appleby furnaces are rebuilt the common centre wall will be restored and the separated checkers will be dispensed with.

In the new melting shop the chambers below ground level are concreted all round, and on the valve-pit side the steel plating, which surrounds the gas flue, is continued up the side of the chamber wall sufficiently far to form a satisfactory seal with the concrete above.

Leakage between two checkers using a common wall can occur, but it is dangerous only when the furnace is cold, *i.e.*, during heating up. There is no danger in the method of heating used at Appleby, as all the checkers are hot enough to ignite any gas leaks before gas is actually put through. In any case, if gas leakages do occur, it is far better that the gas should be burnt in the air checker than that it should leak and pollute the shop atmosphere.

Reversing Valves and Flues

The valves first used by the Company on the tilting furnaces were the Wailes water-sealed type for gas, and the ordinary dry butterfly type for air. In 1930 sliding-damper type valves were installed for ingoing and outgoing gas and outgoing air ; the ingoing air was controlled by dry mushroom type valves fitting on to a machined seat, there being separate adjustment for regulating the air supply going to each end of the furnace. Air supply was by fan, and it was considered that when a furnace required different air inlet-valve openings for each end it was really time the furnace was taken off for repairs. Should differential adjustment be considered necessary at any time the air-fan setting can be varied at each reversal merely by the touch of a wheel.

Since 1936 the spectacle-type air-reversing valve has been used on all furnaces, and is operated by an electric motor with a split hoist drum, which avoids overwinding should electrical cut-outs fail. This type of air-reversing valve is very satisfactory and can well be adopted as a standard design, provided it is watched carefully for stretched ropes.

The problem of gas-reversing valves is not yet fully settled. The original sliding-damper furnace, working on producer gas, had water-cooled valves and seats for the incoming gases as well as for the outgoing products of combustion. Trouble was caused by tar deposition, especially on the ingoing side ; pouring creosote on to the slide valve at intervals of a few hours, and allowing this to burn by the admission of air, was temporarily successful, but the difficulty was eventually overcome by using a dry cast-iron valve with a water-cooled frame. This type was adopted as standard for both gas and air valves on all furnaces. Vertical steel strips are riveted on to each damper, and should one crack inadvertently there is no danger of half a valve being left in the flue when changing takes place.

On the mixed-gas furnaces the ingoing gas-reversing valves were changed to the water-sealed mushroom type. They proved to be satisfactory and are now standard. With clean gases the waste-gas dampers are less satisfactory, and are liable to leak, especially with the modern tendency towards higher gas-port velocities. In this respect they frequently need changing, as once gas commences to leak the valve soon becomes hot and warps, though without leakage long trouble-free runs can be expected. Reversion to water-cooled dampers could be considered and actually the valves were of this type originally, but one or two went dry, owing to stoppage of the water supply, and burst. Immediate changing of the valves was necessary, and it was found that a considerable piece of the flue arch had to be cut out before the valve could be removed, which, of course, wasted far too much time. In a new furnace consideration will be given to the re-introduction of a water-sealed mushroom valve as the gas-waste/gas-reversing valve, and with modern furnaces there should still be plenty of draught available to overcome some loss of streamlining in the flues. The slope of the gas-waste/gas-slide valve has been discussed occasionally. Trials have been made in which the slope leant towards the stack or towards the checkers. The latter is preferred as the valve can be inspected for gas leakages merely by removing a cover plate, and the method has no disadvantages which could be obviated by inclining the valve towards the stack.

In considering the general principle of streamlining in the gas flues there is little doubt that, in theory, advantages must result. In practice two furnaces were changed from Wailes water-sealed valves, with their many corners, to straight-through slide valves, but no extra production could be attributed to this change. Under these circumstances it would hardly be worth spending money to change the design on furnaces already in existence. On the other hand, in a new furnace, if the relative costs were similar, streamlined flues would naturally be put in, as ultimately these would be an advantage, however small. It is believed that maximum streamlining is right, and it is probable that the benefits of the change in a furnace already in existence will not be seen in the normal weekly production so long as a furnace has ample draught, but it is possible that streamlining will enable a furnace to maintain its production when the checkers become clogged towards the end of a run. Therefore, only after examination of several years' working could it be said definitely whether furnace runs had lengthened, and whether production had been maintained at a higher level towards the end of these runs, as a result of the use of streamlined valves.

The flues in the new melting shop are streamlined to the maximum possible for a steel furnace, and an intermediate damper is available, enabling the relative quantities of waste gases passing through the gas and air systems to be subdivided in proportion to the requirements of the checkers. The furnaces have adequate draught, and it is seldom that the chimney dampers are lifted above half the normal height ; therefore, additional resistance could be inserted in the gas flues without detriment to the furnace, if this resistance overcame difficulties caused by frequent changes of slide valves.

In the early mixed-gas furnaces the underground

flues in the valve pit were concreted, as in the producer-gas furnaces. They were quite satisfactory for producer-gas, but when mixed gas was introduced leakages occurred, which ultimately resulted in small explosions taking place underground. Gradually, these explosions became more pronounced, until finally, the whole of the paving in the valve pit would be lifted, and flames would occur at the various cracks and joints, and among the loose earth. To overcome this, arrangements were made to pass the gases from the regulating valve, through an overhead steel tube, to reversing valves situated at each end of the furnace and relatively close to the regenerators. The portion of flue between the water-sealed gas-reversing valve and the regenerator is surrounded by a steel casing, which ensures that there is no possibility of leakage between the furnace regulating valve and the checkers up to valve-pit level, nor, of course, leakage through the slide valve leading to the chimney. This arrangement has been very satisfactory and has obviated the difficulties caused by leaky flues, which, apart from damage by kicks, pollute the atmosphere of the melting shop.

It might be thought that some difficulty, caused by air trapped in this long system, would be experienced when gassing the furnace. In fact, the overhead tube has spring-loaded explosion doors and the gas is passed straight into the furnace simply by opening the normal regulating valve and running out the water seal. No trouble or difficulty with kicks has arisen, and this method is considered to be perfectly safe. (*See* Fig. 18.)

In all steelworks it is essential that the ground surrounding the furnaces should be well drained in order to keep water from the flues. In mixed gas this is particularly important, as any dampness or leakage of water will raise the moisture in the gas entering the furnace and give a non-luminous flame, which is inefficient. Furthermore, it appears to promote foaming charges, but whether this is a direct effect, or is caused by the lower heating power of the non-luminous flame, is difficult to say.

In the main flue to the chimney there are three dampers. The first controls the waste gases passing from the air checkers, the second, close to the chimney, is controlled by furnace pressure and is a vertical type working in a relatively loose slot, and the third is within a few feet of the chimney base and consists of the normal slightly inclined shut-off dry damper in a water-cooled frame which cuts off the furnace completely. The damper and frame can be seen in Fig. 13, on the right of the block of loaded trays in the stockyard.

Lining of the Furnace Body

One of the chief difficulties in the operation of deep-bath tilting furnaces is that of maintaining the front lining, since, in addition to normal thermal wear and charging damage, the effect of tilting the furnace to tap can cause the lining to tilt into the furnace to an angle of 25° beyond the vertical. This means that a weakened lining, which would give considerable further life in a fixed furnace, can completely collapse in a tilter during tapping. (Note that the vertical axis of the furnace cross-section may tilt to 35°, but the outward batter of the steel plate will reduce the angle of tilt of the lining by some 10°).

During 1942 experiments were made on a cold lining, and a summary of the results follows.

Construction—The apparatus consisted of a strong steel base plate which could be slowly tilted to any desired angle. The base plate was surrounded on three sides by a ledge designed to retain the bottom course of brickwork when the plate was tilted. Attached to the fourth edge of the base plate was a vertical plate about five feet high, the angle of which could be varied relative to the base, so that it was possible to simulate varying degrees of outward batter of the furnace plate, or to vary the angle of the main brick joints to that of the outer casing.

It will be appreciated that tests on cold bricks cannot be a complete substitute for trials in the furnace, but the results appear to be of considerable practical value.

Mode of Collapse—In the first tests the base and backing plates were set at right-angles, and on them was built a bonded dry-brick lining, 22½ in. thick and 3 ft. 6 in. long. Linings were built to gradually increasing heights and tilted. A critical change in the mode of collapse was quickly noticed. Linings under 2 ft. 9 in. in height failed as a result of bricks sliding from the base plate in individual courses. Above a height of about 3 ft. though, the whole lining leaned over and collapsed as a pillar. This applied to 3-in. and 2½-in. bricks of silica, chrome-magnesite, and magnesite.

The main indication is, that below a height of 2 ft. 9 in. a strong joining material will increase the possible angle of tilt by preventing the bricks from sliding, whereas above this height the tendency for the lining to overbalance as a pillar will put any joining material under tensile stress, and therefore do little to strengthen the resistance of the lining against possible collapse. As all the linings are above 3 ft. in height it was considered that no bonding for brick joints was necessary, and the practice of setting them dry, merely by sweeping fine dry powder into the joints after laying each course, continued.

Effect of Height—On tilting a lining 22½ in. thick and 3 ft. 6 in. high, collapse occurs at an angle of 22°. Increasing the height to 5 ft. 6 in. causes collapse to occur at an angle of 14°. In the Company's furnace the former angle is safe, but the latter is not.

It is appreciated that the height of the lining does not alter during the furnace run, but if one visualizes material protected at its base by the dolomite bank, so that only 3 ft. 6 in. of bare brickwork shows, the lining will be safe. If, however, fettling is not done properly and the bank height is reduced by 2 ft., the limiting angle of tilt will be reduced to 14°, even if no under-cutting of the brickwork has taken place. This means that unless the lining is supported by good dolomite banks, its stability is materially decreased, even in the case of a relatively new furnace in which the bricks have not worn very much.

Effect of Thickness of Lining—Reducing the thickness of the lining also reduces its stability. The

Fig. 13—Stockyard bay from charging-bench level, showing a charge being assembled. To the right is the furnace-pressure regulating damper. To the left is the structure protecting the instrument cabin

Fig. 14—Stockyard-bay safety fence

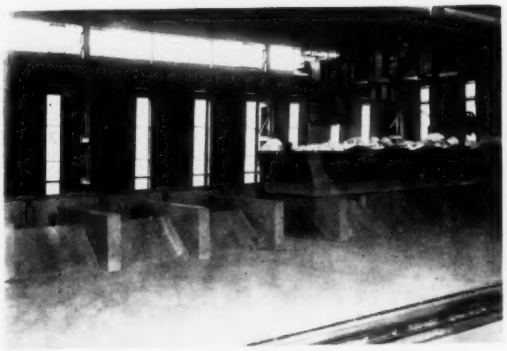


Fig. 15—Box stands on the charging bench. Behind is the stockyard-bay safety fence

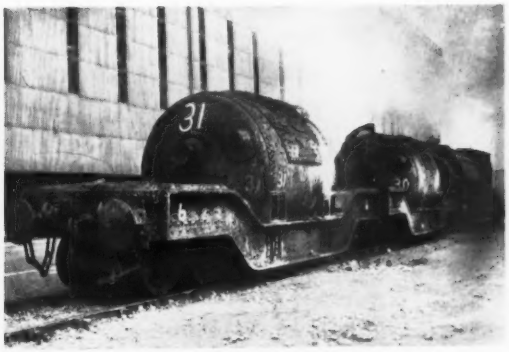


Fig. 16—70-ton hot-metal transfer ladles

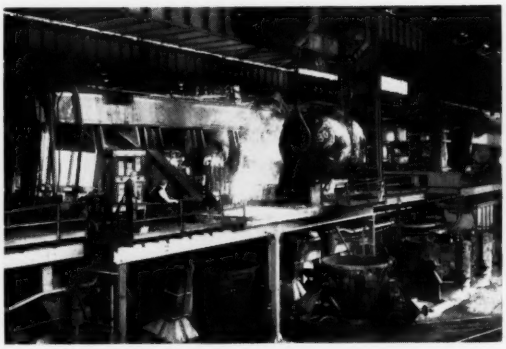


Fig. 17—Charging the mixer. Note the 17-ton slag pans, with 100-ton steel ladles and the stopper drying oven in the background. Part of the main girders, which carry the crane tracks over the full span of the furnace, can be seen

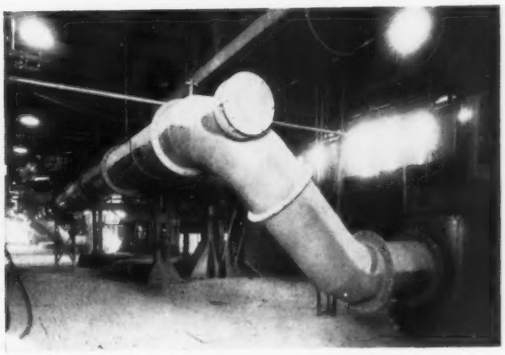


Fig. 18—Valve arch, showing steel gas main, spring-loaded explosion door, and space for removal and refilling of regenerator chambers. The return water main is above the gas main

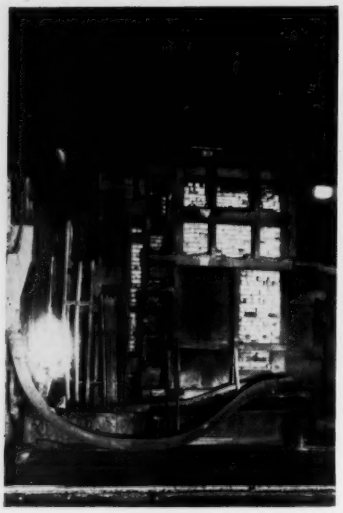


Fig. 19—Original furnace end with very long gas port and trailing flex for returning cooling water from tilting portion of furnace

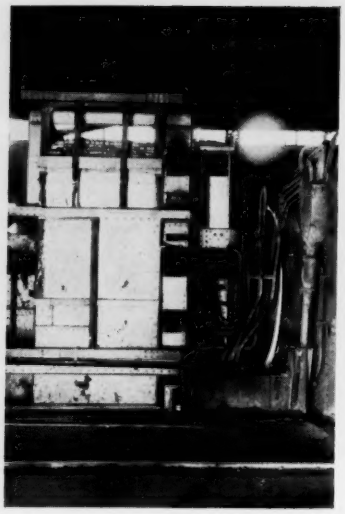


Fig. 20—Modified furnace end with shortened gas port and improved method of returning cooling water from the furnace body

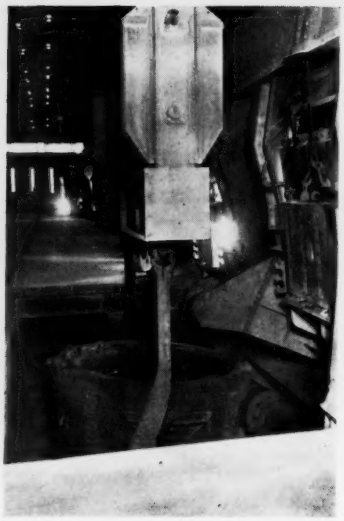


Fig. 21—The ladle in position for taking metal from the mixer. The edge of the sliding stage, which is fully retracted, is on the left of the opening

Fig. 22—General view of the charging side. The mixer is in the foreground

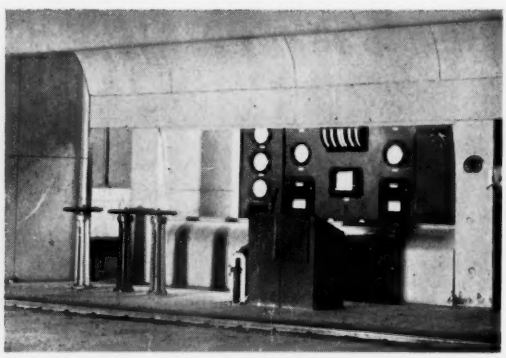


Fig. 23—Instrument panel and control desk

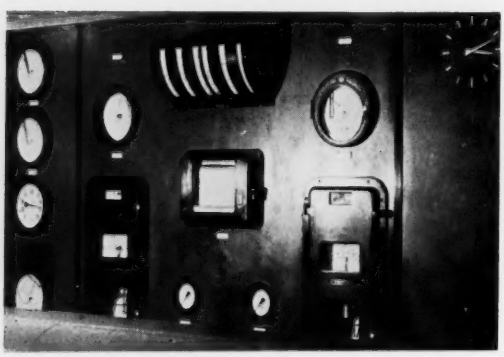


Fig. 24—Layout of the instruments

Fig. 25—General view of the pit side with a furnace tapping in the background. This photograph was taken at night under the normal lighting

Fig. 26—A teeming stand in use

Fig. 27—Stopper operating gear on 100-ton ladles

Fig. 28—Normal setting of the forked cross-head on a 100-ton ladle

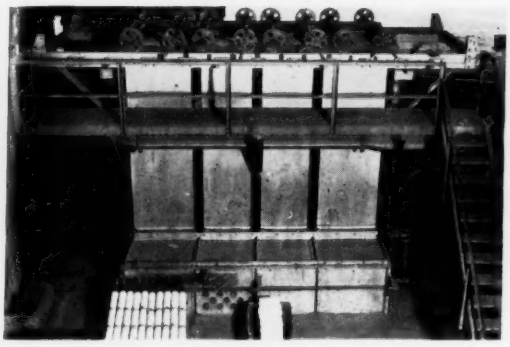


Fig. 29—Stopper drying oven, with hand-operated rolling lids

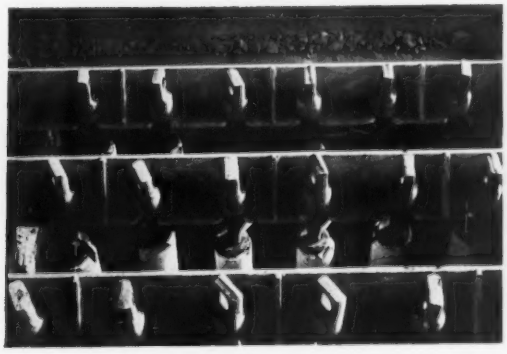


Fig. 30—Stoppers suspended in the oven during drying

Fig. 31—Part of the welfare building

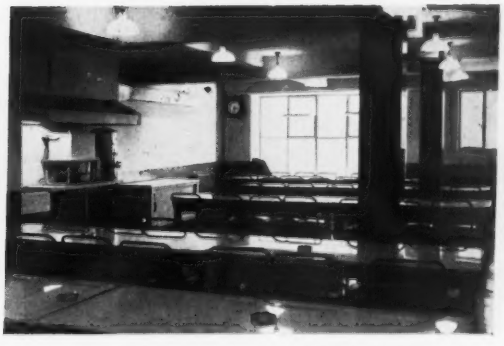


Fig. 32—Part of the mess room

following is an average series for the lining 3 ft. 6 in. high :

Thickness, in.	Tilt Angle (collapse)
22½	22°
18	20°
13½	16°
9	10°

The marked effect of decreasing lining thickness on stability is obvious, and undermining of the brickwork at slag-line level obviously gives a considerable increase in the tendency to collapse.

Effect of Method of Construction—Normally the linings were built with the bricks at 90° (angle θ) to the outer shell of the furnace, and as this leant outwards from the vertical to the extent of 10°, the brick joints struck upwards into the furnace at 10° to the horizontal. The trials consisted of reducing angle θ to below 90°, and the best results appeared to occur when this angle was about 83 or 85°. Under these conditions the angles shown previously for the various lining thicknesses increase by not more than 2° all round. If the angle θ was reduced still further the tilting angle was worse.

In practice another factor, *i.e.*, the support the lining receives by keying with the roof, forbids the possibility of utilizing any prospective advantages which may arise from these conditions. If a lining is carefully drawn out it will be seen that reducing angle θ also lessens the possibility of keying the lining into the roof and, therefore, the lining can tilt, or can be forced away from the casing by expansion. Greatest stability is achieved by a combination of two slopes, the lower being keyed by the dolomite bank, and the upper lining being held between the lower bricks and the roof. To avoid piecing up at the skewback and to strengthen the lining further, a cast-steel skewback and a special block have been designed recently and are shown in Fig. 33. Following several successful trials all the furnaces are now being altered.

These factors in the building have enabled a satisfactory full chrome-magnesite lining to be installed, whereas formerly the lining above the arch was silica, and chrome-magnesite bricks quickly collapsed when tried. These linings have been further improved by the use of a bull-nosed block to assist in bonding the corner of the jambs. The furnaces in the Frodingham Melting Shop have had the angle of the front plating of the furnace reduced from 80 to 77·5°, and so give even greater stability.

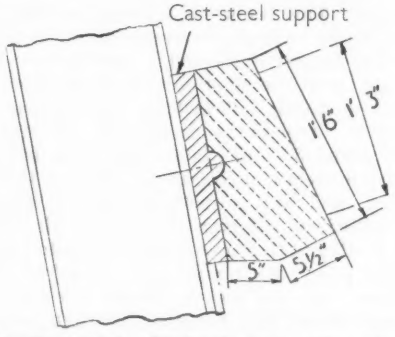


Fig. 33—Cast-steel skewback and silica skewback block for roof

It should be noted that in practice the lining thickness is reduced near the roof, but the general effect of the modifications resulting from these tests appear in an improved front-lining life with fewer production losses caused by bricklaying repairs.

To summarize, the back and front linings are chrome-magnesite from sill level to roof, except for the silica arches which extend over the door width only. Below this level the brickwork is entirely magnesite, the average thicknesses of the sides and bottom being 22½ in. and 14 in. respectively. The doors are water-cooled and fit on water-cooled arch plates designed to give as tight a door fitting as possible, with the additional important advantage of cooling the front buck stays and thereby reducing warping.

The Roof—The roof is built mainly from 15-in. silica blocks with 12-in. ends. The furnace chills are lined and tied into the end rings of the roof. The new-type skewback is shown in Fig. 33.

Ports—There is nothing new in the design of the ports, but the gas-port height has been reduced since the introduction of the original design.

The brickwork is all silica, except for the sides of the air port, a thin coating behind the face-cooling pipes of chrome-magnesite brick, and a facing of chrome-magnesite paste on the lower air-port slope. Water cooling consists of the outer chill ring which is brick-lined, the block-face pipes with connections behind the first course (4½ in.) of the gas-port side walls, and the cooling boxes or pipes in the gas-port back stop.

Various port dimensions have been tried over a number of years, but those shown give good all-round results. The air-port slope is important and cannot be reduced below 8 in./ft. without some effect on furnace performance. The gas-port slope has been varied from 3 in./ft. to level without much apparent effect, and 1–1½ in./ft. has been adopted empirically. With slopes above 3 in./ft. lining damage increases rapidly. Several furnaces that were tried recently in the Appleby shop maintained the gas port at the same width as the uptake, it being reduced by 15° slopes on top and sides to normal dimensions in the interchangeable slice, giving a parallel length of about 3 ft. This still gave satisfactory gas direction in the furnace, but the back portion of the gas port showed the same rate of wear as previously, and needed renewing every five months, instead of ten as before, without any obvious advantages in production or checker preheats.

Gas ports 3 ft. in width have been tried, with the same area, or slightly less, and they are satisfactory in that they do not give appreciable increases in hearth-lining wear, but the ports themselves appear to wear more rapidly, and gas commences to go behind the face pipes before the furnace life is completed.

Steel-Furnace Repair Data

Up to the present each furnace has had one general repair.* The details in Table III are more favourable

* The mixer has not yet been off for repairs.

Table III
FURNACE REPAIR DATA

	A Furnace	B Furnace
Repair time*	1 week 4 days	1 week 6 days
Working time	29 weeks 5 days	27 weeks
Working time, %	94·98	93·56
Total production, tons†	64,469	60,043
Weekly production, tons†	2170	2224
	Bricks, lb./ton	
Silica	20·93	20·94
Firebrick	2·03	1·81
Magnesite	0·27	0·35
Chrome-magnesite	4·41	3·84
	27·64	26·94

* Repair time consists of days off for intermediate repairs, also the time between the end of the run and the finish of the repair which follows, *i.e.*, until the furnace is gassed again
† Production figures include the whole time from the plant starting up as well as a Christmas stoppage

than normal because the furnaces were new, but conversely it is considered that less furnace damage will occur in subsequent runs, when the men become more accustomed to the use of mixed blast-furnace gas and coke-oven gas, and also to keen working furnaces of modern design.

Hot-Metal Cranes and Chargers

Charging in a hot-metal shop should have two distinct flow lines separating solids and liquids, the best method consisting of ground-type rotating chargers and overhead cranes. Overhead chargers are considered unsatisfactory. The relative quantities of the materials charged are not always appreciated, and an analysis of the figures for a 300-ton charge follows :

	Tons
Molten iron from mixer	225
Cold scrap to steel furnaces	78
Oxides to steel furnaces	42
Limestone and lime to steel furnaces	27
Oxides to mixer	12
Limestone to mixer	11
Total cold	170

Thus, although the bulk of the charge is hot metal, much of the charging time is spent on the cold materials. In the new shop the number of machines is excessive as there must be a stand-by against possible breakdown. The basis for a full shop, with 6 furnaces and 2 mixers producing 550,000 to 600,000 tons/yr., will be four chargers, three 100-ton hot-metal charging cranes, and three 20-ton cranes in the stock-yard bay. At present there are two of each of these for a production of 210,000 to 220,000 tons/yr. The capacity of the main hoist of each hot-metal crane is 100 tons, and that of the auxiliary hoist 20 tons. The hoists work on separate crabs, and the long-travel speed is 150 ft./min. These cranes normally handle the 60-ton hot-metal transfer ladles from the mixer, but if necessary, they can also pick up the 70-ton ladles from their carriages in the north-end annexe, and thus transfer metal from blast-furnaces to steel furnaces, should the mixer be out of operation at any time.

Each charger has a capacity of 4 tons, and a long-travel speed of 400 ft./min. The original chargers had chains, or rack and pinion drives, for the cross-travel. Both types were unsatisfactory, and the new plant has plain driven wheels running on rails, which have so far been most satisfactory. Figure 21 shows metal being taken from the mixer, and Fig. 22 shows a general view of the charging stage and machines.

Method of Charging

The normal method of charging the furnaces has been described in detail previously, but it is repeated very briefly here for reference.

When tapping has been completed the furnace is tilted towards the charging stage so that the tap hole, which is on the bottom of the furnace, is exposed to enable it to be closed. At this stage the furnace contains anything from 20 tons upwards of molten steel, and from 10 to 25 tons of slag. During tapping no slag is removed from the furnace ; thus this quantity represents the whole of the refining slag from the previous charge. After closing the tap hole the furnace is fettled lightly along the base of the back bank and ends, and is then taken level to commence charging.

Five boxes of burnt lime (3 tons) are spread uniformly over the bath, and are followed by the remainder of the oxides and limestone, which are charged as nearly as possible in uniform alternate layers. The hearth is fettled, and, after allowing the requisite time for burning in, the scrap is charged ; usually all of it can be put in at one operation, as the local scrap used is relatively heavy, and really light materials have already been charged in the mixers.

The linings of the tilting furnaces are completely backed by steel plate, and it is impossible to renew the brickwork without taking the furnace off for repairs. During each charge and immediately after the scrap, it is the practice of the furnacemen to fettle the linings with chrome-magnesite paste. Most of these repairs are obviously necessary on the front lining, because of minor damages which are caused mainly while charging scrap.

The furnace is allowed to heat up for a short period, and then approximately 50 tons of molten mixer iron are charged. This is allowed to work for some time, after which the bulk of the remaining mixer metal is added. The furnace is allowed to melt for four to five hours, and then the final calculated adjustment of limestone is made, followed by the molten metal necessary to complete the charge, this quantity being normally about 50 tons. Some little time before the bath is completely melted, samples for slag and metal are taken, and any adjustments of limestone, or further additions of mixer metal are made, and the furnace is allowed to proceed until completely melted.

At this point the temperature is taken, and if satisfactory, slag and metal samples are sent to the laboratory while the furnace is tilted, and the primary slag removed as completely as possible. By the time this has taken place the analytical results

will have been received, and calculated additions of limestone, oxides, and molten mixer metal are added. When these are completely melted, the bath is on a good boil, and the temperature is satisfactory, the furnace will normally be ready for tapping. This is confirmed by samples, which have been sent to the laboratory at appropriate times, and by temperatures taken with the quick-immersion thermocouple. The average tap consists of removing three 100-ton ladles in rapid succession by tilting the furnace.

Since the publication of previous descriptions certain changes in method have taken place, the most important being :

(i) Some increase in silicon and sulphur in the iron, caused by deterioration in the quality of materials available for iron making

(ii) The introduction of mixed blast-furnace and coke-oven gases for firing the furnaces (in place of producer gas), bringing in the very important difficulty of foaming.

The first has resulted in increased difficulties of operational control and more bottom troubles, and in the second, mixed-gas firing has caused a reduction in outputs compared with producer-gas firing. A considerable amount of work has been devoted to finding the causes of foaming, and it appears to become increasingly prevalent when the following conditions obtain :

(i) High-hydrogen gas
(ii) Non-luminous gas flame in the furnace—which results from low gas-checker temperatures or high moisture in the gases
(iii) High-silicon iron
(iv) Use of dirty (siliceous) scrap
(v) Cold charging
(vi) Use of aluminous oxidizing ores.

The use of producer gas, or oil, to increase the luminosity of the flame helps materially, but there are no producers in this plant, and oil, although it is being installed, is not yet available. The trouble has been considerably reduced recently by charging one ladle of about 50 tons after the scrap has been warmed up, and allowing this to almost work itself out, which takes some two to three hours. The main metal addition of about 100 tons follows, and finally, the remaining 50 tons is added some four to five hours later, together with any extra limestone addition rendered necessary from analyses made on the 150 tons of metal already charged. Splitting of the charging of the first 150 tons of metal has made a most important contribution towards the increased outputs obtained, and although it increases the amount of organization necessary in a large shop to avoid delays, it is certainly well worth while.

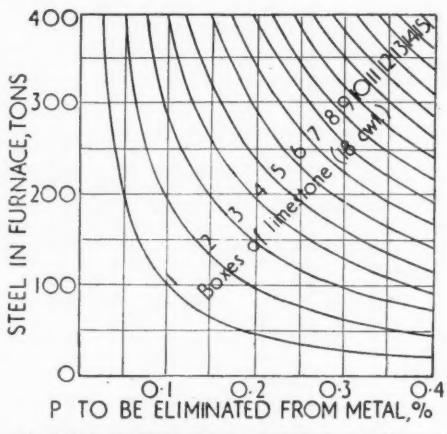


Fig. 34—Slag control chart showing additions to be made after removal of primary slag

Table IV

LIMESTONE ADDITIONS REQUIRED (18-CWT. BOXES)

Boxes of Limestone to add with Last Metal before Slag-Off

With Si, %	150	175	200	225	250	275
<0·2	1	1	1	1	1½	1½
0·21–0·3	1½	1½	2	2	2½	3
0·31–0·4	2	2½	3	3½	4	4½
0·41–0·5	3	3½	4	4½	5	5½
0·51–0·6	3½	4	4½	5	5½	6½
0·61–0·7	4½	5	5½	6	7	8
>0·7	5	6	7	8	8½	9

Metal and Limestone to add before Slag-Off

With Slag Iron, %	Tons	Boxes
6·0– 6·9	20	3
7·0– 7·9	20	2
8·0– 8·9	20	1
9·0– 9·9	20	...
10·0–10·9	25	...
11·0–11·9	30	...
12·0–12·9	35	...
13·0–13·9	40	...
14·0–14·9	45	...
>15·0	50	...

Boxes of Limestone to add for Slag Iron at Slag-Off, and Slag Left On

Slag Iron	10 Tons Slag	15 Tons Slag	Extra Metal Boxes of Limestone for Every 20 Tons Si, %	Boxes
<6·9	+4	+6		
7·0– 8·4	+3	+5		
8·5– 9·9	+2	+3		
10·0–11·4	+1	+2	<0·15	3½
11·5–13·9	...	...	0·15–0·50	4
14·0–16·0	−1	−2	<0·50	5

Refining, based on slag-control methods already described,* is entirely controlled by the first melter, in accordance with the chart and instructions shown in Fig. 34 and Table IV. Although this practice has been criticized subsequently by several writers from a theoretical angle, it has certainly been accepted by the men as a considerable improvement, and is always employed. It has satisfactorily produced several million tons of ingots since its introduction, without additional technical staff.

Operational Control

Charging is controlled on a time basis by using a series of standardized charges covering the varying scrap/metal ratios and charge sizes. Each charge type has a specified time for each of the main operations, so that when the furnace taps the times for finishing each portion are recorded on the furnace sheet. The furnaceman is not compelled to finish at these times, but he must record the reasons for the total number of minutes behind schedule. These time losses are checked with the standard time for every charge, are coded, and are summarized daily, weekly, or, according to charge type, as desired.

* A. Jackson, *Journal of The Iron and Steel Institute*, 1944, No. I, pp. 49P–66P.

The net refining time is calculated by :

$$\text{Interval slag-off to tap} - \frac{\text{molten iron added}}{\text{production rate, tons/hr.}}$$

These figures are summarized weekly for furnaces and monthly for operatives. The average times for the weekly averages vary between 75 and 90 min.

In all melting shops there is a gradual tendency for tapping operations to 'bunch' together, with consequent bad effects on the continuity of mill operations. After each tap the sample-passer records a 'bunching index' which is based on the following considerations :

(i) If all steel furnaces tapped at uniform intervals the ingots could be charged into the soakers with little heat loss

(ii) As furnaces tap more closely together so increasing quantities of steel go cold while awaiting space for charging into the soakers

(iii) A figure which shows, according to the time between taps, the product of tons and time for steel waiting to be charged into the soakers at average mill operating rates. This figure is positive when steel is waiting to be charged, but negative if the soakers are waiting for hot steel.

(iv) The sample-passer reduces the positive figure by adding extra mixer metal to the furnace during refining, in order to put back the tapping time. If the furnace is allowed to wait and waste time so that a low bunching index results, an immediate reaction is shown in an increase in the net refining time ; thus full control is possible.

(v) The negative figures, indicating soakers waiting for a tap, are the responsibility of the planning staff, who, looking ahead for up to 36 hr., should have charged a small charge into one or more furnaces to reduce tap-to-tap time and so distribute the tapping operations more evenly.

The spreading of tapping operations is of considerable help to the melting shop, since the charging and pit-side congestion, which occurs with bunched tapping, is avoided. The result is found in increased output, especially when all the furnaces are working together. It should be noted that the foregoing methods are not very important in the new melting shop, but they are extremely valuable in the Appleby plant, with productions averaging over 11,000 tons/week. There is no doubt that some methods of this kind are essential, and they can be used with advantage in large tilting-furnace melting shops.

Tapping carbon is estimated from a time/carbon graph. When the additions made after slag-off are melted and the bath temperature is within, say, 20° C. of tapping, what is normally the tapping sample is sent to the laboratory and the carbon content is plotted against time on a graph. A carbometer sample is taken at the same time, and, from then on, further samples are taken at intervals of exactly ten minutes. These results are added to the graph and, at whatever time the furnace taps, the sample-passer can immediately estimate the carbon by extrapolation of the graph. Any colour or combustion carbons can be plotted as checks on the graph at the time they are taken. This method obviates doubts as to the carbon content, which can arise when tapping, owing to the well-known plus or minus variation of analytical methods. The graph and the charge sheet are returned to the office after tapping, and the carbometer samples are retained for combustion checks if subsequent results render this necessary. The normal analysis and quick-immersion temperatures are, of course, standard practice. A typical charge is shown in Table V.

SUMMARY OF FIRST FULL YEAR'S OPERATION

Table VI contains a summary of the first 52 weeks' working, commencing from the starting of the plant.

Table V

TYPICAL CHARGE

Time	Operation	Boxes			Pans of Slag	Slag Fe, %	C, %	P, %	Mn, %	S, %	Si, %
		Lime-stone	Oxides	Lime							
12.50 p.m.	Finished tapping										
3.00	Finished oxides and lime-stone	17	27	5							
3.45	Finished fettling and burning in										
5.30	Finished scrap, 75 tons										
6.30	Finished pasting linings, etc.										
7.30	Finished first metal, 50 tons							1·22	0·55	0·068	0·26
9.35	Finished second metal, 100 tons							1·19	0·50	0·070	0·25
1.30 a.m.	Finished last metal, 50 tons	3						1·24	0·52	0·065	0·28
4.00	Bath sample					6·5	0·19	0·15	0·20	0·052	
4.25	Extra metal, 20 tons	3						1·27	0·50	0·065	0·31
5.45	Bath sample temp., 1580° C.					8·5	0·20	0·09	0·17	0·049	
6.10	Slag-off				2½						
6.20	Extra metal, 20 tons	7									
7.05	Bath sample, 1562° C.					11·7	0·21	0·046	0·17	0·045	
7.15	,, ,,			1			0·19				
7.25	,, ,, 1573° C.						0·17				
7.35	,, ,,			1			0·16				
7.45	,, ,, 1581° C.						0·15				
7.50	Tapped pit samples						0·21	0·041	0·58	0·043	
8.00	,, ,, ,,			1			0·22	0·040	0·59	0·042	
8.10	,, ,, ,,						0·20	0·043	0·61	0·041	

For comparative purposes a summary is also given of the working from January to November, 1948, to exclude the first few weeks of starting-up, and the Christmas stoppage.

The average analysis of the slag produced, taken from the daily slag-off figures, is :

SiO_2	8·8%
Fe	8·1%
Total P_2O_5	17·44%
Soluble P_2O_5	16·24%
CaO	48·36%
Solubility	93·1%

The standard raw-materials consumption of the furnaces is :

	Cwt. ton
Mixer metal	15·70
Heavy scrap	3·96
Light scrap	0·10
Pit scrap	0·67
Finishings	0·19
Oxides	2·70
Limestone	1·60
Lime	0·18
Fuel	3,995,000 B.Th.U./ton

An analysis of the gases consumed by the furnaces is :

	Coke-Oven, %	Blast-Furnace, %
CO_2	2·3	10·0
Illuminants	3·6	...
O_2	0·5	...
CO	7·6	26·3
H_2	52·4	3·3
CH_4	29·4	...
N_2	4·2	60·4

INSTRUMENTATION

Equipment for oil or pitch/creosote firing is being installed, but exclusive of this is the following instrumentation which was designed approximately 2½ years ago :

(1) Automatic pressure regulators for the incoming coke-oven and blast-furnace gas, with recorders
(2) Temperature recorders for the gases
(3) Meters for both gases
(4) Meter for air volume
(5) Stack-draught recorder, and indicator showing the pull on the furnace before the stack-pressure regulating damper
(6) Furnace-pressure recorder
(7) Automatic furnace-pressure controller, with hand-wheel adjustment on panel
(8) Roof-temperature recorder
(9) Air and gas-checker-top temperature recorder
(10) Stack-temperature recorder
(11) Recorder showing temperature difference between air checkers, and a signal which operates when the difference exceeds a preset figure
(12) Air/gas ratio controller, with adjustable hand wheel on the panel
(13) Indicators showing pressures at the top and bottom of each regenerator and blast-furnace gas-mains pressure
(14) Immersion-pyrometer outfits
(15) Carbometer
(16) Telephones on each furnace connected to the laboratory, the weighmen, and the manager. The line to the laboratory is used most frequently.
(17) Push-button automatic-sequence gas and air reversal.

The instruments under groups (1) and (2) serve the whole shop, the mains being made of adequate size so that changes in flow to one furnace have no effect on the gas supply to the remainder. In conjunction with these there are total gas-consumption recorders for the whole shop. The remaining instruments are fitted on all furnaces and the mixer.

Figures 23 and 24 show the appearance of the panel. In the foreground of Fig. 23 can be seen the indicator desk which carries the door-operating and reversing push buttons and indicator lights. The lid seen hanging on the desk, when in position, covers all the control buttons and acts as a safety device by preventing accidental operation of the doors when men are working on the operating gear. The vertical group of instruments on the panels to the left of Fig. 24 will relate to oil firing when the panel is completed. The roof-temperature indicator has now been installed under the clock on the right. On the

Table VI
PRODUCTION DATA

Total Weeks	Nov. 1947 to Nov. 1948		Jan. 1948 to Nov. 1948	
	A Furnace 52	B Furnace 52	A Furnace 44	B Furnace 44
Stop weeks	1	1	...	...
Non-working repair time, weeks	2·4/7	3·3/7	2·4/7	3
Working weeks	48·3/7	47·4/7	41·3/7	41
Production per working week, tons	2243·2	2267·3	2269·8	2310·5
Total production, tons	108,776·40	107,860·35	94,035·65	94,732·20
Average weekly production on 52 weeks basis, tons	4166·09			
Average production for last 44 weeks, tons			4494·48	
Average weekly production, excluding repairs and stop weeks	4510·5		4580·3	
Total production, tons	216,636·75		188,767·85	
Maximum ingots cast in one week			3177·25	3148·4
Maximum week equated to 168 hr.*			2874·48	3018·3
Dolomite consumptions: tons†	6031·85		5167·1	
lb./ton	62·37		61·32	

* The plant works continuously for 168 hr./week
† The dolomite consumption is the total weight received at the plant, and, of the figure shown, some 12 to 14 lb. are estimated as the mixer usage

central panel two circular instruments at the top indicate chimney draught and roof pressure. The lower two are dials which show the automatic furnace pressure and the gas/air ratio ; in between are the buttons for manual operation of the damper. Clarity with boldness is necessary in the presentation of results, especially in the glare normally found in a melting shop. In the case of the most constantly watched instrument, the roof pyrometer, its indication should be accurately visible under melting-shop conditions, and to anyone with moderate eyesight when working at the furnace. A slight liveliness in the pointer, indicating the delicacy of the instrument, is desirable, but not a constant swing covering upwards of 10°. It was found that with an indicator of this type the men were soon using it with interest, whereas, with records only shown on a continuous chart, a very much worse job was made of keeping the roof temperature within the prescribed limits, as the instrument could only be read by approaching it, and often the older men required spectacles to examine it.

Automatic roof-temperature control could obviate some of this difficulty, but even this would not eliminate the advantage of the dial-type indicator. The remaining instruments, using automatic controls, require observation less frequently, and present-day instruments appear to give the requisite clarity of record or indication.

Occasionally it has been suggested that the panel arrangement is somewhat elaborate. It was designed on the principle that an attractive panel draws attention to itself. Every effort is made to keep it clean, attractive, and well-lighted, and the cost of the extra refinements, compared with the plant as a whole, is extremely small.

Use of Instruments and Automatic Control

The furnacemen came from a non-instrumented shop, and, with this fact in mind, the basis for the instrumentation might well be derived from the following quotation from a lecture to the Melting Shops Metallurgical Society* :

> " More cases could be shown but these two illustrate the point that instruments are merely the servant of the furnaceman *if he knows how to use them*. To do this he must be able to correlate the figures shown with what he sees in the furnace and he should be able to judge from the appearance of the furnace whether the instruments are showing any appreciable inaccuracy. *In other words the furnaceman adjusts the furnace controls to give what in his opinion are the best conditions and the instruments then continually adjust all controls to retain these pre-set values.* Periodic checks by examination of the furnace are necessary to see that the correct conditions are being maintained but in general instrumentation makes it much easier to retain uniform conditions continuously."

The shop has been operating only for one year and there is still much to learn, but the following practices have been standardized :

(i) The air-checker temperature is kept in balance continuously by adjustment of reversal times.

(ii) The gas-checker temperature is maintained over 1050° C., and preferably within the range 1075–1250° C., by adjusting the partition of waste gases between gas and air regenerators ; the individual ends are balanced by the admission, when necessary, of a small quantity of live gas into the downtakes.

(iii) The furnace pressure is maintained automatically at 0·055–0·065 in. W.G. The actual reading varies from furnace to furnace, probably owing to differences in pipe-line temperatures, etc. For individual furnaces it is set by the shop manager on ' flame sting,' when the charge is quietly refining, and is retained at this point.

(iv) The gas/air ratio control is maintained at 1·0, which is equivalent to 0·75 cu. ft. of air per cubic foot of blast-furnace gas, and 5·0 cu. ft. of air per cubic foot of coke-oven gas. This ratio resulted from setting the gas and air to give the best flame in the furnace, and the fact that the ratio dial showed a theoretically correct figure was purely fortuitous. The operatives were originally at liberty to alter the ratio if they thought a better result could be achieved, but after a few trials they settled down to this figure, which is now fixed. Record tonnages were made with this particular ratio.

(v) Blast-furnace and coke-oven gas consumptions are constant for given valve openings because of regulated supply pressures.

(vi) Tapping temperatures are governed by a scale based on the steel quality being produced.

(vii) At present there are four different roof-temperature measuring combinations (of pyrometer and recorder), all of which appear to be sufficiently accurate to be really useful control instruments, but no two show the same temperature when the roof burns, the difference being up to 80° C. In practice each furnace is set by the ' experts ' getting together, deciding when the roof is hot, and noting this figure as the danger point. Unfortunately, occasions arise when the roof burns at, or below, this temperature, or conversely, does not burn at much higher temperatures. It appears possible for a normally cool roof to be heated for a short time well above its burning point without apparent damage, but with maintained temperatures, even below this point, it will rapidly melt, without any alteration or adjustment to the instrument. Under these conditions it is not yet possible to fix arbitrary limits until further knowledge is acquired.

(viii) While charging cold materials the coke-oven-gas consumption is increased to 110,000/120,000 cu. ft./hr. which is nearly double the normal figure. With automatic pressure and gas/air ratio control, this gives improved rates of production, which are not achieved with corresponding gas volumes on furnaces without controls.

Proposed Developments in Control

In due course it is hoped to develop a suitable link up between roof temperature and fuel input, should further trials with the present apparatus indicate it to be possible or desirable. The advantages are realized, but more of the possible disadvantages of fully automatic control are now known.

* A society formed by the Company's employees. The lecture was circulated privately.

Table VII

TYPICAL AVERAGE INSTRUMENT READINGS

		A Furnace	B Furnace	Mixer
Coke-oven gas consumption, cu. ft./hr.		65,000	68,000	48,000
Blast-furnance gas consumption, cu. ft/.hr.		164,000	166,000	248,000
Air flow, cu. ft./hr.		451,000	465,000	426,000
Checker temperatures, °C.	Gas	1085–1237	1071–1214	1018–1186
	Air	1047–1147	1031–1125	1034–1148
Stack temperature, °C.		405	397	387
Gas-checker pressures, in. W.G.				
On gas:	Bottom	+0·045	+0·020	+0·175
	Top	+0·260	+0·250	+0·365
On stack:	Top	−0·675	−0·580	−0·530
	Bottom	−1·030	−1·050	−0·910
Air-checker pressures, in. W.G.				
On air:	Bottom	−0·090	−0·120	−0·175
	Top	−0·005	−0·007	−0·001
On stack:	Top	−0·470	−0·490	−0·405
	Bottom	−0·830	−0·710	−0·735
Chimney draught, in. W.G.		−1·180	−1·170	−0·960
Furnace pressure on recorder, in. W.G.		+0·057	+0·058	+0·061

Every day an assistant manager examines each instrument, notes the steady reading obtained, and decides, as nearly as possible, whether the instrument is reading correctly in accordance with the prevailing operating conditions. He records the figures, and Table VII gives averages taken over about four weeks. The pressures vary considerably with the working of the charge, the stack rising to 1·65 in. during charging, and falling to as low as 0·75 in. during refining or foaming. Similarly, the coke-oven gas, blast-furnace gas, and air volumes vary, and so do the checkers' temperatures to some extent. The furnace pressure is kept as constant as possible.

Although the stack temperature, which is taken midway across the stockyard bay, appears rather low, it is a true recording, since the waste-gas flues at each end of the furnace seldom show appreciable redness until nearly the end of the reversal. The furnace pressure is given as shown by the recorder, the criterion being 6–9 in. of sting showing at all doors. The chimney draught is taken on the furnace side of the regulating damper, but in each case the damper controlling the air/waste-gas flues is partially lowered to give the checker-temperature distribution as shown in Table VII. These temperatures are measured by thermocouples inserted through the chamber roof over the centre of the checkers.

Pit Side

The pit-side bay is 60 ft. wide and is served by two 140-ton overhead casting cranes with 25-ton auxiliary hoists. The hoisting speeds are 7 ft./min. and 25 ft./min. respectively, and the long travel speed is 150 ft./min. (*See* Figs. 25 and 26.)

Casting takes place from 100-ton ladles suspended on the cranes, or from the teeming stand. This teeming stand has an adjustable cross-travel trolley enabling four ingots to be teemed on one car when necessary. The upper frame, which carries the ladle, travels inwards to fill the other line on the drag of moulds. The longitudinal travel is below stage level. The train of cars is pushed along by an electrically operated pusher on the side of the track. At present the moulds in use are of 4-ton capacity and are set with four per car. It is expected that later the standard mould size will be increased to 6 tons.

The double stoppers on the ladles are operated by a very strong stopper gear. The stopper rods are secured to the cross-head by a screwed nut, which in addition to its normal purpose, is used for suspension while carrying and drying the stopper, thus ensuring that the stopper sleeves are not disturbed by bumping on the ground during the handling which occurs between making and setting in the ladle.

The stopper drying oven is set on the pit side between *B* furnace and the mixer (*see* Figs. 29 and 30). It is of simple design, and is fired by means of a single jet of blast-furnace gas admitted through a 1½-in. pipe, seen on the right of Fig. 29. In the same photograph can also be seen the nine holes in front of the oven which admit extra cooling air to the gases before they enter the oven proper. The stoppers are prepared as shown, and are lifted into the oven by an overhead crane. Figure 30 shows stoppers suspended in the oven during drying, and the nut used for suspending, lifting, and setting the stopper is clearly visible. The oven is built to hold a maximum of 60 stoppers in 10 rows of 6, and can easily supply the shop when working to full capacity.

The ladles are dried by coke-oven-gas jets. The nozzles for the ladles are of 11 in. length and are rammed from outside, being secured in place by a triangular-shaped nozzle box. The nozzle box has a protruding collar of the same length as the nozzle spigot, and when the ladle is new this collar faces inwards. As the bottom wears thin the nozzle box is reversed, thus reducing by 2 in. the distance that the box protrudes through the ladle bottom, thereby compensating for the reduction in the thickness of the bottom. This renders it unnecessary to have two lengths of nozzle for any given diameter. As a well is normally not used around the nozzle inside the ladle stopper, setting must be very accurate. The gear used is rigid, and it has proved so satisfactory that running stoppers are almost unknown. The ladle cross-arm can be rotated on a tapered bolt and the

lateral adjustment of the stopper is obtained by the use of a forked end. The details can be seen in Figs. 27–30.

OPERATIVES AND TRAINING

When technicians, designers, and constructors have done their best and the plant is ready to work, the degree of its success depends on the operative staff. The fundamental factor for successful steelmaking is co-operation between technical management and operatives, and up to the present this has been successfully achieved. The men were transferred from an old shop with producer-gas-fired furnaces of 135/180 tons' capacity which were practically without instruments, to fully instrumented 300-ton furnaces fired with mixed coke-oven and blast-furnace gas. The even tenor of the old shop was resumed within a few days of the change-over, but with nearly double the output rates. Superficially, the change to the new shop took place in one day, only about 12 hr. elapsing between the last tap on the old and the first on the new, and the same men worked in equivalent positions in both plants. Actually, the change-over commenced over 12 months before the new plant was finished, and involved lectures and instructions on the new plant and the methods of operation, the placing of redundant men, the discussion and completion of new rates and duties, followed by the last-minute rush when men spent their days off learning to drive new machines, ramming hearths, and doing the thousand and one jobs necessary to bring the whole plant into operation at once. Continuity of operation was essential or the mills would have been stopped for ingots. The change-over was most successfully accomplished, and the two furnaces made their first taps within four hours.

In these days of intensive research many seek the 'fool-proof' furnace, and others, who demonstrate the greater outputs attainable when the furnace is surrounded by skilled technicians, publish their findings in a language which the operatives (including the manager) seldom understand. Conversely there are others whose ignorance of the industry is so colossal that they think all good things are due to the man on the furnace and know nothing of the technical and administrative background.

Fortunately, in most melting shops, there is a bond between manager and man which enables them to progress steadily. The most important function of this bond, at the present time, is to translate the findings of the scientist into the language of the operative and thus bring into practice some of the vast amount of knowledge available.

For the last eight or ten years all men intending to become melters have first to pass the Operatives' Examination of City and Guilds of London Institute, having obtained instruction from evening classes and courses run at the works. After this, further classes are taken at the men's discretion, and during the winter months they run a Melting Shops Metallurgical Society which deals essentially with their particular sphere of work, or that of associated departments. Periodic meetings of groups are held to give instruction on particular aspects or changes in operative technique, and the men attending receive full reports of these lectures, which appear to be well studied and discussed.

To some the foregoing remarks may appear to be out of place in a technical publication, but it is considered that in spite of instrumentation and other similar changes, more of the recent increases in production have resulted from improved skill in the operator than from any other single cause.

Welfare

The Company no doubt leads most steelplants in the incorporation of the most up-to-date ideas. Showers, washrooms, and messing facilities are available, with the customary individual locker, and provision is made for the drying of clothes. (*See* Figs. 31 and 32.)

The shop itself was painted in colours advised by appropriate experts, and after 12 months' use the paint is still good, except for dark spots where damage by heat or fume was to be expected. The plant is illuminated by alternate metal-filament and mercury-discharge lights, set in pairs on swinging jibs so that they can be cleaned easily from the gangways. On the charging stage the intensity is estimated at 8 to 10 ft.-candles, in the stockyard bay at 7 to 8, and in the pit at 7. The stockyard bay and the pit are, of course, at lower levels. The shop itself has sufficient windows to render artificial lighting unnecessary on normal days.

To further the general policy of improved working conditions the furnacemen's cabin, in front of the instruments panel, is fitted with air-conditioning devices and is glazed with heat-absorbing glass, thus avoiding any possible discomfort from furnace radiation. Those who have worked in melting shops and know how enthusiasm wanes with increasing fatigue towards the end of a hot shift, will appreciate the benefits derived from anything which reduces the rate of energy loss. The men in this plant are certainly very appreciative of the high standard of working conditions and are obviously doing their best to maintain them.

MISCELLANEOUS OPERATIONAL DEVELOPMENTS

Auxiliary Heating for Gas Checkers

Some six years ago efforts were made to overcome low flame luminosity, one of the major troubles with mixed blast-furnace and coke-oven gas-fired furnaces, by burning live coke-oven gas in the outgoing gas checkers to keep up the temperature. A great deal of controversy centres around the efficiency of this method, but it does increase output and reduce heat consumption per ton in this type of practice.

In all open-hearth practice high flame velocity is advantageous, and this, with mixed-gas firing, means either a small port area or low-calorific-value gas. Both tend to give poor flame luminosity, small port area because insufficient heat passes to the gas checkers on waste heat to crack the hydrocarbons adequately, and low-calorific-value gas because it loses luminosity owing to the high content of nitrogen and carbon dioxide. If the gas preheat can be maintained at the desired figure a good luminous flame can be attained at all stages of operation, and through-

out the whole furnace campaign. Several methods of gas admission have been tried, but practice has shown that the minimum gas is required when it is added in the uptakes just behind the port ; thus, the main extra heating is in the uptake and slag pocket. There is normally insufficient air available to burn more than a small amount of gas, and this method of admitting gas just behind the port is, therefore, important. At first, attempts were made to add gas in the checkers, but the air available did not burn enough gas to give the requisite additional preheat, and extra gas merely passed to the stack unburnt. In tilting furnaces it must be remembered that some air is always leaking into the waste gases through the bottom of the joint between the fixed and tilting portion, and hot gases should tend to leak slightly at the top.

The gas for heating is led through the back of the gas-port stop about 3 ft. above stage level, through four pipes of 2 in., 1½ in., 1½ in., and 1 in. dia., controlled by ordinary plug cocks with handles riveted on, so that it can be seen at a glance whether the cocks are open or closed. The pipes are always fully open or fully closed, and each has a separate entry into the uptake ; thus a strong gas jet is driven into the stream of waste gases. Formerly the gas entered through one opening, the disadvantage being that at low volumes it travelled down the wall and burned it away rapidly. The various pipe sizes enable a choice of heat quantities to be obtained simply and certainly, and repeated at will. The furnaceman has a table showing all possible combinations of pipe sizes, set in order of increasing volume, and by reference to this table he can easily change at once to the grouping above or below the one in use. The grouping of the pipe sizes can be seen immediately from the position of the handles. Plugs can be removed on the bends between cocks and uptake to ensure that the openings have not been covered by fluxed brickwork. No appreciable increase in uptake wear has been found with this method of operation, and it is only towards the end of a campaign that anything above a 1½ in. pipe is ever necessary. Each end is adjusted separately according to the checker temperature shown on the recorder.

Some adjustment of gas- and air-checker temperatures is possible by dampering the flues, but if this is done excessively the high waste-gas velocity into the gas port causes it to wear very rapidly and so spoil the direction of the incoming flame. Back-stop wear is also very rapid.

Heating up after Repairs

Various methods of heating up have been tried, and though they were considered to be as rapid as safety would allow, the preliminary warming takes 18 to 24 hr. All operators are aware that if a hot furnace roof is patched, and heating is by hot air resulting from shutting the damper for 2 or 3 hr. before putting gas back again, little spalling of the new brickwork takes place. Recently published work has also shown that it is possible to heat up silica bricks quite rapidly, under favourable circumstances, with little likelihood of damage. Efforts were made, therefore, to simulate the heating by hot air. This is done by firing coke-oven gas into all four regenerators from the valve-pit side, some eight to twelve courses below the top of the checkers, and with the damper down. The waste gases pass upwards from the checkers and slag pockets to the furnace, and this large volume of brickwork controls the rate of rise in temperature of the gases entering the furnace. Here, the pressure is sufficiently high to blow waste gases out under all doors and also upward between all roof-brick joints, thus heating the bricks all round and forcing steam outwards from the furnace.

This method is by far the best, and brings up the temperature of the roof, without any spalling, in a relatively short time. The practice has been standardized, and heating-up instructions have been issued, of which the following points contain all that is necessary to describe the operation for this particular size and type of furnace :

(i) The chimney damper is closed and the doors are propped up 3 in. above the sill.

(ii) All valves are put on centre, the air fan is started, and air is admitted through the gas system by opening all doors available.

(iii) There are two 1½-in. gas pipes through each gas-checker wicket, and two 2-in. pipes in each air checker. These are lighted to give a flame about 12 in. high on each pipe, and are left for 2 hr.

(iv) These pipes are gradually opened to a maximum which is reached 8 hr. from commencement.

(v) After 12 hr. a 6-in. dia. pipe is inserted through the back of the gas-port wicket and lighted, after

Table VIII

RATIO BETWEEN SPECIFIED CHARGE SIZE AND PRODUCTION RATE

Charge Size,* tons	A Furnace		B Furnace		Both Furnaces	
	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.
275	5	13·98	8	14·09	13	14·06
250	171	15·05	181	15·20	352	15·13
225	39	14·45	40	14·79	79	14·62
200	25	14·08	19	14·91	44	14·44
175	17	14·29	13	15·26	30	14·71
150	14	14·13	11	15·79	25	14·85
	271	14·76	272	15·11	543	14·94

* The variation in charge sizes should be noted, these variations being used normally to space out tapping

Table IX

EFFECT OF SILICON CONTENT OF CHARGE ON PRODUCTION RATE

A Furnace

Silicon Range, %	Charge Size, tons													
	150		175		200		225		250		275		Total	
	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.
Under 0·19	3	14·94	10	14·47	13	14·58	15	15·45	62	15·62	1	14·00	104	15·32
0·20–0·29	3	14·21	4	15·60	7	13·44	16	14·07	65	14·90	2	12·82	97	14·64
0·30–0·39	5	13·88	1	14·20	3	13·72	4	13·79	24	14·69	1	16·60	38	14·45
0·40–0·49	2	12·50	2	10·85	1	16·39	3	12·68	15	14·41	..	..	23	13·79
0·50–0·59	1	15·92	..	..	1	10·80	..	..	5	13·31	1	13·67	8	13·12
0·60–0·69	..	..	..	..	..	..	1	13·03	..	..	..	..	1	13·03
Total	14	14·33	17	14·29	25	14·08	39	14·45	171	15·05	5	13·98	271	14·76

B Furnace

Silicon Range, %	Charge Size, tons													
	150		175		200		225		250		275		Total	
	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.
Under 0·19	6	13·77	7	15·41	7	16·01	14	15·42	64	16·12	3	14·64	101	15·78
0·20–0·29	4	16·10	2	14·15	8	14·67	14	15·12	70	14·95	2	13·08	100	14·94
0·30–0·39	1	26·67	4	15·55	3	13·55	6	14·38	28	14·64	2	12·37	44	14·78
0·40–0·49	..	..	..	..	1	13·15	6	12·96	13	14·14	..	..	20	13·74
0·50–0·59	..	..	..	..	..	..	..	..	6	13·33	1	17·91	7	13·98
0·60–0·69	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Total	11	15·79	13	15·26	19	14·91	40	14·79	181	15·20	8	14·09	272	15·22

setting the valves for gas and air on that end and raising the damper. The gas in this pipe can be increased rapidly, and within an hour the furnace will be at a bright-red heat.

(vi) Reversal takes place each hour, so that in 18 to 20 hr. full normal gas can be put through the checkers, and the furnace can be manned ready for charging in 24 to 32 hr. from the commencement of warming, according to the size of the furnace and the extent of the repair.

(vii) The warming pipes are left in the air checkers until they reach 900° C., but the gas pipes are normally shut off when the furnace is fully gassed.

The heating-up time saved is 6 to 12 hr., and the roof is more satisfactory.

Gas Cut Off During Reversal

On occasions, considerable discussion has arisen over the desirability of cutting off the gas supply to the furnace during reversal. Many years ago this principle was installed for the Company's mixed-gas furnaces on the advice of outside designers, when the use of these gases was first commenced. The conclusion which has now been reached is that there appears to be no real benefit to be gained from the use of this apparatus, for the following reasons :

(i) The total reversing time of the gas valves is approximately 5 sec., which is equal to only 0·55% of the total time between reversals

(ii) The volume of flues, checkers, slag pockets, and uptakes is approximately equal to one minute's supply of gas to the furnace, *i.e.*, equal to approximately 6·7% of the total gas used

(iii) Approximately 12 times as much gas passes to the chimney from the checkers themselves as the quantity lost directly during actual reversal of the valves.

Examination of the furnace showed that the flame appears to take 45 sec. after reversal before it reaches anything approaching its normal size, and in actual fact the time necessary for the flame to develop fully must be between 1¼ and 1½ min. With any device used to cut off gas during reversal, even if automatic, the loss must be a further 5 sec. for each opening and closing of the valve, and these times can be added to the time that gas is out of the furnace.

A further important disadvantage is that, when the gas is shut off, the gas-pressure regulators will partially close and the re-opening of these valves, after reversal is complete, further increases the time before the furnace is back on its full gas supply. If the supply pressure of the blast-furnace gas is greater than that of the coke-oven gas then, during the period the shut-off valve is closed, blast-furnace gas will be forced back down the coke-oven gas main and thus will cut off the coke-oven gas supply to the furnace for an even longer time, while the main is being cleared. Conversely, if the coke-oven gas pressure is the greater, the first rush of gas, after reversal is complete, will be mainly coke-oven gas, and should any kick occur in the flues and checkers it will be considerably more damaging than normal. This is much more likely to be serious than should the same conditions arise with blast-furnace gas.

It was suggested that shutting off the gas between reversals would reduce kicks in the chimney flues, but in practice this is not the case. It may be that the kicks are slightly less in intensity but they are still damaging, and give increased porosity in the flues. This difficulty has been obviated by the use of the pilot lights in the flues, mentioned elsewhere. Apparatus for shutting off the gas by hand lever was installed, but it is not used. Should shutting off of the gas be required, rapid and automatic valves should be used, as hand operation is far too slow.

Effect of Certain Variables on the Rate of Production

The figures in Table VIII include all charges from the commencement of the plant to 18th September, 1948, except those with excessive hot-repair times, which were produced in the first twelve days of operation, and which followed general repairs. Mixed blast-furnace and coke-oven gas was used throughout.

The 250-ton charge gives the best results, with the usual tendency to fall away to about 200 tons. A rise usually occurs after this because small charges are normally used when a considerable volume of steel from the previous charge remains in the furnace ; hence the normal routine of fettling is abbreviated, with advantage to the production rate. The missed fettling will be made up on the subsequent normal

Table X

EFFECT OF CHARGING TIME ON PRODUCTION RATE

Time, min.	Charge Size, tons											
	150		175		200		225		250		275	
	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.	No. of Charges	Average Production, tons/hr.
Under 149	2	21·30	..	..	..	..	..	..	..	..	..	..
150–199	10	14·49	3	15·53	1	17·04	..	..	..	..	..	..
200–249	8	13·17	11	15·62	15	14·77	14	15·01	24	16·11	..	..
250–299	4	13·95	9	13·96	11	14·75	26	15·42	109	15·27	2	14·17
300–349	..	..	1	14·28	7	14·32	26	13·94	90	15·14	1	13·24
350–399	1	12·81	4	14·20	1	13·76	7	14·86	53	14·76	5	13·43
400–449	..	..	1	15·96	4	15·49	3	13·51	29	14·90	2	15·33
455–499	..	..	1	13·15	4	12·50	1	10·99	31	15·23	2	14·63
500–549	..	..	..	..	1	11·35	2	12·93	12	14·12	..	..
550–599	..	..	..	..	..	..	..	..	4	13·54	1	14·00
	25	14·85	30	14·71	44	14·44	79	14·62	352	15·13	13	14·06

Table XI

EFFECT OF SILICON AND CHARGING TIME ON PRODUCTION RATE, USING 250-TON CHARGES

Charging-Time Range, min.	Silicon Content, %															
	Below 0·19		0·20–0·29		0·30–0·39		0·40–0·49		0·50–0·59		0·60–0·69		Total			
	No. of Charges	Production, tons/hr.	No. of Charges	Production, tons/hr.	No. of Charges	Production, tons/hr.	No. of Charges	Production, tons/hr.	No. of Charges	Production, tons/hr.	No. of Charges	Production, tons/hr.	No. of Charges	Production, tons/hr.		
Below 250	9	16·03	8	15·34	3	15·08	1	14·22	3	14·00	:	:	24	16·11		
250–299	33	16·19	38	15·17	21	14·89	14	14·29	3	13·14	:	:	109	15·27		
300–349	28	16·01	36	15·00	17	15·18	5	14·70	4	13·26	:	:	90	15·14		
350–399	22	15·02	23	14·74	5	13·84	3	14·51	:	:	:	:	53	14·76		
400–449	15	15·41	9	12·91	2	15·02	2	14·67	1	12·09	:	:	29	14·90		
450–499	16	15·67	11	15·14	2	14·28	2	13·15	:	:	:	:	31	15·23		
500–549	2	15·47	7	14·02	2	14·37	1	11·49	:	:	:	:	12	14·12		
Above 550	1	12·45	3	13·90	:	:	:	:	:	:	:	:	4	13·54		
Total	126	15·87	135	14·93	52	14·66	28	14·28	11	13·32	:	:	352	15·13		

charge. Previous experiments have shown that if the smaller charges are used continuously, the production rate falls in line with that given by the larger charges.

Specified charge is the term applied to the charge as ordered. To it can be added an average addition of 50 tons of mixer iron for adjustments to the bath composition before and after slag-off. The drop on the 275-ton charge represents only a few charges, but indicates a trend, since when a 275-ton charge is specified the furnace must have been almost emptied, except for slag at the previous tap, and this is a recognized reason for lowered production rates.

The effect of silicon on the metal from the mixer is of more significance, and to illustrate this the two furnaces are considered separately in Table IX.

The figures in Table IX are sufficiently uniform to allow a summary for the two furnaces to be made :

Silicon Range, %	No. of Samples	Tons/hr.
Under 0·19	205	15·55
0·20–0·29	197	14·79
0·30–0·39	82	14·64
0·40–0·49	43	13·77
0·50–0·59	15	13·66
0·60–0·69	1	13·03

A study of these data emphasizes the important effect of silicon on furnace output, and shows a loss of about 3·4% production, based on the middle of the range, for each 0·1% increase in silicon. This effect would be far greater if mixer-iron variations were not compensated for by the slag-control methods used.

The effect of charging time on production rate can be seen in Table XI.

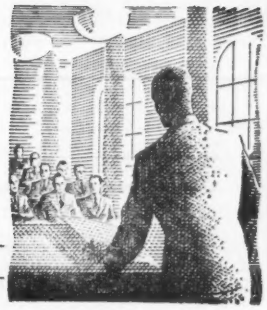
The large group of 250-ton charges indicates the necessity for charging as rapidly as possible to obtain the maximum output, and this group is sub-divided, in Table XI, to show the effects of charging time and silicon. It will also be seen from Table XI that the important effect of silicon on output is again in great evidence.

It is probable that the figures in Tables IX, X, and XI are insufficient to give a true statistical picture, but, for practical purposes, they give a good relative idea of the importance of silicon, charge size, and charging time on production rates. They especially demonstrate the value of adequate mixer capacity and low-silicon iron.

Acknowledgments

The author wishes to thank the Appleby-Frodingham Steel Company for permission to publish this paper, which is written at this relatively early date to enable additional and unpublished experiences so far obtained to be made known to others who are at present engaged on similar types of problems. He also acknowledges all those who have assisted in designing, building, and operating what, today, must be one of the world's finest plants.

DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

AUTUMN GENERAL MEETING, 1948

THE AUTUMN GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 10th and 11th November, 1948, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, Sir Andrew McCance, LL.D., D.Sc., F.R.S., was in the Chair at the first three sessions, and Dr. C. H. Desch, F.R.S., Past-President, on the Thursday afternoon.

The Report of the Meeting was published in the March, 1949, issue of the *Journal* (pp. 187–190).

The discussion on the first group of papers is given below. The remaining discussions will be printed in the July and August issues of the *Journal*.

Discussion on the Paper—

A NOTE ON THE VARYING-TURBULENCE COWPER STOVE,*

by Daniel Petit

Monsieur **Petit**, in presenting his paper, said: I wish to take this opportunity to stress one important point. The present paper includes the design of an appliance which I have designated 'C.S.I.' and which is intended to form part of the ancillary plant of the large-capacity blast-furnaces now being built in France. I would remind you that the following conditions governed the design of the stoves:

Coke consumption per 24 hr.	600 tons
Blast temperature	700° C.
Ability to cut off the gas supply to the stove for 8 hr. per day.	

Some of you may have thought that the dimensions of the stoves arrived at are relatively large—they have, in fact, a diameter of 8 m. and a height of 33 m. It is obvious that one could at once reduce these dimensions by forgoing the ability to cut off the gas supply for 8 hr., but it is a particularly important point which I want to emphasize, especially before an audience in Great Britain.

These designs have been based on what I will call 'the Continental mode of operation,' comprising two Cowper stoves in action and one in reserve. I know that in Great Britain many plants work with three stoves, two on gas and one on blast. That I will call 'the British mode of operation.' This, of course, does not imply that on the Continent there are no blast-furnaces fed by three stoves, nor, no doubt, that there are no furnaces in Britain supplied by two stoves only.

To make a choice between these two modes one must obviously take into account the equipment of the works and their operating conditions. Here, only general rules can be laid down.

Let us first consider the simple case of a single blast-furnace of large capacity fed by independent stoves. The Continental mode of operation could be applied in two ways:

(1) Only two stoves of large diameter would be built. The cost would be low, but there would be no reserve.

(2) A reserve is wanted, so in this case three large stoves must be built, and that is very expensive.

The British mode of operating provides a reserve, at relatively low cost and with excellent efficiency.

I studied the matter very thoroughly before proposing to French metallurgists who wish to adopt it, the Cowper stove which I have called 'C.S.II.' with a diameter of 7 m. and a height of only 32·50 m. These stoves have been designed in such a way that if an accident happens to one of them the blast supply is assured by the other two. When three stoves are in operation together it is theoretically possible for each one to accumulate calories corresponding to a working period of $3\frac{3}{4}$ hr., under the above assumption of a coke consumption of 600 tons per 24 hr., and a blast temperature of 700° C. This means that with three C.S.II. Cowper stoves it would easily be possible to cut the gas off for 8 hr. per day.

The total weight of refractories in a C.S.II. Cowper stove is 1336 tons, a figure that is comparable with those which I have given for the construction of a C.S.I. stove. Table A summarizes this comparison. The 'British' solution seems to have definite advantages. It is much cheaper if a reserve is required, and it offers greater overall security, in that, in case of accident, two hot stoves are immediately available to feed the furnace.

With combustion chambers of reasonable size, burners each capable of using the whole of the gas supply can be employed; then peaks of not less than 200% of the theoretical total consumption can be dealt

* *Journal of The Iron and Steel Institute*, 1948, vol. 160, Oct., pp. 131–138.

Table A

	'Continental' Solution : 2 Stoves in Action		'British' Solution : 3 Stoves in Action	
Dimensions of the Stoves	8 m. × 33 m.		7 m. × 32·5 m.	
On the basis of coke consumption of 590 tons/24 hr., blast temp. 700° C., and dome at 1200° C., each stove constitutes a theoretical heat reservoir for—	$5\frac{1}{4}$ hr. blast With 2 stoves in action gas can be cut off for 8 hr.		3 stoves in action $3\frac{3}{4}$ hr. With 3 stoves in action gas can be cut off for 8 hr.	2 stoves in action in case of accident to any one In this case gas cannot be cut off for 8 hr.
Evaluation of the costs on the basis of total amount of refractories required—	1st Variation 2 stoves built : 3340 tons approx.	2nd Variation 3 stoves built : 5020 tons approx.	3 stoves built 3930 tons approx.	

with. This solution has, on the other hand, the minor disadvantage that it leads, no doubt, to rather greater thermal losses, but that can be remedied by more careful insulation.

Some of you may think that these ideas on the use of Cowper stoves as heat accumulators are rather revolutionary and that they are of only secondary interest. I do not know the situation in British iron-works well enough to offer an opinion on this point, but I can tell you that in France this is very much a burning question of the day. Several investigations on the subject have been published recently, and one of the reasons for the success of our Cowper stove on the Continent lies precisely in that ability to serve as a large heat accumulator and to determine the heat reservoir that will be available under different conditions of operation.

In integrated works, including, for example, rolling mills, it is generally very valuable to be able to dispose of an excess of gas of 20–25% per shift. In works comprising only blast-furnaces, the gas is generally used to generate electricity ; the cost per kilowatt varies considerably according to the number of hours during which it is supplied, so that in most cases the provision of a heat reservoir is of very great interest. The results obtained at Denain-Anzin and the calculations that I have just submitted to you are enough to work out this heat reservoir with sufficient precision. That, I think, is their chief interest.

Mr. **I. S. Scott-Maxwell** (British Iron and Steel Federation) : In some respects it is a little difficult to discuss the tests described in this paper, because, as far as I know, similar work has not been carried out on stoves recently built in this country, and therefore one is somewhat at a loss for a detailed basis of comparison. Efficiency tests were, however, made shortly before the war, on a new three-zoned stove which was almost the same size and capacity as the stove which the author describes. The average efficiency over a period of 71 days, calculated from a datum temperature of 60° F. (15·56° C.), was 89·4%. This compares favourably with the Denain stove.

I mention particularly the long period of test and the figure for datum temperature to allay any fears that the author may have as regards the accuracy of the figure, because it is appreciated that the efficiency can vary depending on the heat stored in the stove at any given moment. These tests, however, did not include an investigation into heat-storage capacity, which is a point that the author emphasizes.

In the Denain stove, the principle of varying turbulence has been used in a simple and rather ingenious manner. I think it is generally agreed that the idea behind the use of a varying-turbulence design is sound, the problem in any stove being to transfer the heat from the hot gases into the brickwork as efficiently and as rapidly as possible. There are, in effect, two main considerations to be kept in mind in any stove design : (i) The provision of a large heating surface per unit volume of checker-work, to promote efficient and adequate heat transfer, and (ii) the provision of sufficient brick volume to allow adequate thermal storage. The first condition, I would suggest, is probably the more important, because the bricks will hold a great deal of heat if only it can be got into them. The principle of varying turbulence should assist this heat transfer, but I cannot assess from the figures given in the paper to what extent this is so.

Figures 4, 8, and 9 of the paper show the distribution of temperature in the stove, and not heat, as stated. From these diagrams it has been possible to calculate the heat storage, which results in a very large figure, but it so happens that this particular design of checker gives a very high ratio of heating surface to checker volume, the ratio being approximately 18. In the British stove which was tested before the war the comparable ratio was 9·6, neglecting the horizontal passages. In each case the actual weight of checkerwork is very similar—640 tons for the French stove and 646 for the British stove—but the French stove is some $7\frac{1}{2}$ ft. higher and 3 ft. larger in diameter. The increased surface area is obtained by a greater number of checker spaces.

The author shows in Fig. 7 the temperature distribution, taken from German sources, of a stove which obviously will have a smaller thermal storage capacity, but we do not know the ratio of heating surface to checker volume, nor the volume of checkerwork per unit of checker space. Surely it is these factors which determine whether the maximum-charge curve is concave or convex. I am inclined to believe, therefore, that the curves shown in Fig. 7 are not comparable with those shown in Figs. 4, 8, and 9.

On the general question of providing a large thermal storage in a stove, I do not understand why this is so essential to Continental operation as distinct from British

or American. The author, in his introduction to the paper, has partially answered the question. As far as the blast-furnace is concerned, it does not seem to me to be good practice to take the gas off the stoves for 8 hr. under any conditions. A blast-furnace sometimes demands excessively high rates of heat input, and requires everything that the stove can give it, while at other times the furnace takes very little heat ; but unfortunately one never knows when this is going to happen.

At a plant with which I was recently associated, it was originally the practice to take the gas off the stoves for short periods in order to satisfy a peak demand at the steelworks, but this finally had to be altered, because frequently after such a period, with the stoves low in heat, the blast-furnaces suddenly demanded an abnormal quantity of heat, which they could not get. The result was that the furnaces were soon in difficulty, and it sometimes took days, if not longer, to get back to normal.

In conclusion, I should like to ask the author four questions : Firstly, can the author explain more fully why the conditions in the French works are such that it is necessary to take the gas off the stoves for long periods ? Secondly, with regard to Fig. 7, is the ratio of heating surface to checker volume as high as it is in the Denain stove ? Thirdly, can the author distinguish between the effect on thermal-storage capacity of the varying-turbulence principle as such, as distinct from the surface-heating ratio ? Fourthly, would it not be possible to design an ordinary zoned stove with a comparable ratio of heating surface to give the same thermal storage as the Denain stove, irrespective of the principle of varying turbulence ?

Major **W. R. Brown** (Messrs. Ashmore, Benson, Pease and Co., Ltd.) : The general impression which I get from the paper is that the author sets store on having achieved a performance which is not generally required in this country. This difference in requirements was explained in his presentation of the paper. Hot-blast stoves in this country and in the U.S.A., are designed on the assumption that a constant supply of gas is available. Nevertheless, I suggest that many modern stove installations in this country could function in the manner which the author describes if they were called upon to do so, though I could not say whether their performance would compare favourably or otherwise with the figures given in his paper.

Some of the results recorded in the paper give an exaggerated impression, *e.g.*, a stove which we should regard as capable of handling 60,000 cu. ft./min. of blast is tested when handling only 21,000 cu. ft./min. ; heat is stored by attaining a dome temperature of 1280° C., which we should regard as too high for the proper preservation of brickwork ; while the flame temperature to achieve the performance is derived from gas with a calorific value of 112 B.Th.U./cu. ft., which is richer than is available here. The test where the stove was blown for 11½ hr., Fig. 5, is to my mind an interesting freak, but it has little value in assessing the true worth of the stove. A better conception is gained from Fig. 6, which shows a very admirable performance, but not one which is revolutionary in character ; its value would have been better understood had we known the volume of blast which was blown at the time this test was taken.

It is quite common to find high efficiency and high heat-storage capacity in any modern stove installation in this country, even if only because of the fact that stoves are designed to meet the maximum conceivable demands in regard to volume and temperature. Therefore, as under all average conditions the stoves are operating considerably below their designed rating, good figures of efficiency are obtained.

On page 137 the author states : " If the gas consumption of all the services is regular it would be desirable to use lightly charged stoves working at maximum efficiency." That is precisely the practice in this country and there is no need for abnormal storage of heat.

The author makes certain unsupported statements which I do not readily accept as indisputable. He says that round holes lead to bad utilization of refractory material. The designers of a well-known stove checker with round holes have demonstrated that 96% of the brick is effective. The author states that the checkers should be without lateral intercommunicating channels, because the waste gases leave the combustion chamber at such a rate that they tend to sweep towards the side of the stove opposite the combustion chamber. He argues that horizontally interconnected checkers become heated irregularly and so are not used efficiently. My own observations lead to an opposite conclusion ; the signs of hardest usage occur near the combustion chamber, and I fail to appreciate the reference to irregular heating or how the self-regulation and chimney effect, of which the author speaks, come about.

I like the construction at the top of the checkers shown in Fig. 2, where they are raised in tiers. This ought to help the distribution of the gases, but I am far from convinced that the flow can be even, unless the gas can disperse laterally after having entered the passage-ways.

The comparison between the Denain temperature curves and those shown in Fig. 7 is hardly admissible ; in one case the stoves have a checker column 85 ft. high, and in the other 55 ft. high, and so the heat storage must obviously be very different. It would be more interesting to compare the performance with that of a modern stove of equal size if the relevant figures were available.

I would like to know whether the references to ' average ' blast temperature mean actual ' straight-line ' temperatures held by mixing cold blast with the hot blast. If it is the practice to use straight-line temperatures on these very protracted blows, where enough heat is stored to blow the furnace for 8 hr., surely the quantity of cold blast needed to reduce the initial temperature to the straight-line figure must be large. It would entail the use of larger mixer mains than we now use.

On page 138 it is stated that the cast-iron grid, columns, and girders, for a stove 26¼ ft. in dia., weigh 39½ tons. Designs in this country weigh about the same, or slightly less, so this is nothing very novel.

The author states that the combustion chamber is constructed of refractories that do not suffer after-contraction. From Table VI we find that this section is built of brick containing 30–35% of alumina. We, in this country, would like to have a similar brick which is free from after-contraction and at the same time free from spalling.

I was disappointed to find that the author showed no drawing of the actual checker blocks. He refers to a block with five holes, from which I inferred that they are cruciform in shape, a fact which he has since kindly confirmed. I think that an illustration would have been informative because, apart from the scientific efficiency of a checker, we must consider its constructional robustness. If a checker is cruciform in shape, it may present certain difficulties in making a good contact with the periphery lining, because, if they have to be cut to meet the curve of the lining, some rather awkward shapes may result.

It is a pity that observations on a paper of this kind must seem to be critical. I hope that the author will appreciate that this is inevitable if we are to dissect his work in a reasonably intelligent manner. Will he please

take our inquisition as a compliment to the interest he has aroused.

Mr. **M. W. Thring** (British Iron and Steel Research Association) : First of all, I should like to query with the author this question of varying turbulence. I cannot see why you would not do just as well with a stove which had the bricks of the type shown in Fig. 1, *EF* and *GH*, the whole way down the furnace. I do not understand why you want a region in which there is a low heat-transfer coefficient and then suddenly change over to a high heat-transfer coefficient ; it seems to me that it would be better to have the high heat-transfer coefficient the whole way down.

Secondly, is it genuinely varying turbulence or simply varying surface area per unit volume which comes in here ? The shape of the holes in the bricks is worked out very carefully, and I see that that is very important, but the chief point is that one type of brick has a greater surface area than the other, and I am not sure that it is not simply that, and not turbulence. It would be very interesting to construct a water model of this particular stove and to see whether it is mainly turbulence or just variation of surface area that counts.

Another very interesting point in this paper is what the author says about the Cowper stove being such a wonderful means of storing energy. Dr. Ritchie, of the British Coal Utilisation Research Association, once suggested that the problem of fluctuating loads in boilers should be got over by having a brick heat-storage system. For instance, in a colliery boiler, where the steam requirement varies rapidly with a time period of the order of half-an-hour, a brick stack between the fire and the water would enable heat to be stored and used when the load suddenly went up. It would be very interesting to follow that up and to decide whether this is the cheapest way of storing energy. I imagine that it would be cheaper, for the same amount of energy, than using a gas-holder. The principle should be worthy of further development.

AUTHOR'S REPLY

Monsieur **Petit** wrote in reply : To deal first with Mr. Scott-Maxwell's remarks, the paper indicates the insignificance of efficiency trials in most stoves. Very different results are obtainable from the same stove by varying the quantity of heat stored when each trial is made. The useful surface of a stove evidently is of great importance, but in many cases it is very different from what may be called the ' apparent surface '—I am thinking of stoves that have, for example, triangular openings, and in the corners there is no circulation of air or gases. In the design of the varying-turbulence stove I have tried to use the whole surface of the bricks, and that must be one of the reasons for the results obtained.

Many modern zoned stoves have such small openings that, in my opinion, they will be partly blocked by falling pieces of bricks and mortar. This means a reduction of surface, efficiency, and heat storage.

Very few diagrams determining the distribution of heat in stoves have been made ; all those that I have seen have the general appearance of Fig. 7, taken from a German document.

In answer to Mr. Scott-Maxwell's last question, I would refer him to my introductory remarks in presenting the paper for discussion. It seems to me that the possibility of storing heat is an advantage in almost any work ; this advantage can be greater or smaller, according to conditions. In any case, the securing of a ' costless gas-holder ' is always worthy of consideration.

Replying to Mr. Thring's comments, I would say that fillings with star-shaped openings have been used in Germany, with worse results than with plain openings, owing to the small useful surface of the fillings, the gases circulating mostly in the centre and not in the corners. The shape of the full-charged curve (curve I, Fig. 4) would seem to be the best confirmation of the advantages of varying turbulence. I am in complete agreement with Mr. Thring on the advantages of a ' costless gas-holder.'

The final sentence of my reply to Mr. Scott-Maxwell is also my first answer to Major Brown. In my opinion the working conditions with low charges and short periods of blowing are contradictory to the statement that with round holes 96% of the material is effective. The work carried out and the calculations made on stoves have proved that the quantity of ' working material,' *i.e.*, the refractory used to exchange calories, is rather thin around the holes ; it is, however, very much thinner when the periods of blowing are shorter. It is also noticeably thinner on the under part of the stove. For these reasons the figure of 96% seems to be exaggerated. Round holes have, in fact, been generally abandoned, although bricks with round holes are easier to make.

I think the Denain trials are the best proof of the action and of the usefulness of the ' chimney effect,' whether the gases have a tendency to flow more at the outside, *i.e.*, opposite the combustion chamber (which I have observed) or in any other way.

In all modern layouts, cold-air mixers should be installed. They are easily designed so that the stove can be used as an accumulator, and the cost is small compared with the advantages obtained.

The weight of a cast-iron grid depends largely on the duty which it has to perform ; a rough comparison of weights has little significance.

The cutting of bricks depends on the shape of the mantel. With polygonal mantels it can be avoided, but these give rise to other disadvantages.

A great deal of work can still be done towards the improvement of stoves. My paper is intended as a contribution to this work.

Finally, I wish to express my thanks to the Directors of Denain, who have given me the opportunity of making the trials, and to the contributors to the discussion for their interest in them.

Discussion on the Paper—

MAGNETIC CONCENTRATION EXPERIMENTS UPON IRON ORES USED IN NORTH LINCOLNSHIRE PRACTICE,* *by L. Reeve*

Dr. **L. Reeve** (Appleby-Frodingham Steel Co., Scunthorpe), in presenting the paper, said : I must apologize for an arithmetical error in the paper in the section dealing with the ore concentration factors. On p. 276, second column, concentration factor No. 2 should be altered to read as follows :

* *Journal of The Iron and Steel Institute*, 1948, vol. 159, July, pp. 275–280.

Concentration Factor Number	Original Ore	Concentrate Only	Concentrate +Middlings
2	...	$\frac{46{\cdot}4}{31{\cdot}7} \times 76{\cdot}4 = 112$	$\frac{40{\cdot}7}{31{\cdot}7} \times 89{\cdot}8 = 115$

Six lines lower down, in the same column, 76·2 should read 76·5.

These alterations reduce the concentration factors for the original laboratory tests slightly below the concentration factors obtained in the kiln (*see* Table III of the paper). The kiln is therefore slightly more efficient than the laboratory furnace.

A further point, which is not sufficiently emphasized in the paper, is that the middlings can be separated, as desired, to any degree from zero upwards, by altering the magnetic flux in the magnets, or alternatively, the distance of the belts from the magnets. The richness of the concentrate can be varied in this way and it is possible to produce concentrates approaching 50% in Fe content, but at the expense of a loss of iron yield. A certain amount of work has been done on middlings in the hope of concentrating them further, but it is too early yet to make any definite statement on whether that will be possible on a large scale.

With reference to the economics of the process, though the potential economies in the use of concentrated ore are very large, the cost of concentration is fairly high, particularly if it is recalled that in order to make one ton of iron, more than four tons of ore must be roasted. It is too early yet to say whether it will be economically justifiable to install the process on a large scale in this country.

Dr. **H. L. Saunders** (Imperial College of Science and Technology, London) : It is always interesting to see these laboratory techniques developed to the pilot-plant stage, but I have noticed in many cases that there tends to be a certain degree of finality about the pilot plant, which I think is a mistake. The author has not adopted that course ; this plant is obviously one where provision has been made for a great deal of flexibility, and for the kind of control which, I am sure he found from his laboratory experiments, was likely to be necessary. I think that the results which he has obtained are very promising indeed, and although, at the moment, the benefit seems to be more with the Lincolnshire than with the Northants deposits, there is no reason why suitable means should not ultimately be found for attacking the problem in its larger aspect if followed up by alternative methods.

Ore concentration is a subject which is coming more and more into prominence today, particularly in this country ; firstly, because of the deterioration in the quality of our home ores, and secondly, because we have ores which it would not prove economical to mine unless they can be concentrated in some way. In the present state of our knowledge, it seems most unlikely that any single method could be universally applicable, for, as Dr. Reeve has pointed out this morning, there is a great difference in the types of our ores.

I think that the author has made a wise choice in selecting magnetic roasting for a preliminary study, because this kind of plant is relatively straightforward in character. Moreover, it is capable of a great deal of variation in processing temperature. Again, there is freedom of choice in the selection of the atmosphere in the two chambers, which can be either reducing, oxidizing, or neutral. Further, a plant of this type is economical on power and maintenance. When we remember that concentration is only part of the beneficiation process, since the material will probably be made into sinter later on, it will be seen, as has already been pointed out, that cost is a very important factor. The margin is not a large one, unless very substantial fuel economy can finally be achieved in the furnace.

When considering the concentration of bedded ores which are to give a self-fluxing burden, there would be no point in extracting one constituent by going to the extent of completely upsetting the slag composition. On the other hand, one type of ore may respond favourably to silica extraction, while another, perhaps treated by an alternative process, might give tailings high in lime, so that by blending the two concentrates thus obtained the overall slag volume could be lowered very substantially. The author has said that this is one of the processes which he has under consideration. Beyond the standard methods of ore dressing, I do not know what he has in mind, but wonder whether any hydrothermic treatments along the lines of greatly accelerated natural weathering have been considered. It seems a possible and interesting line of attack. Whatever process is adopted, however, the high tonnage of the materials to be treated imposes serious limitations, if the necessity for intermediate handling arises at any stage in the process. This is where a scheme such as the author has adopted, with a very compact type of plant, is likely to score a definite advantage.

Most of the ferruginous minerals are paramagnetic to some extent, but they vary enormously in degree, and, since any separation process depends on the differential, very intense fields will be required. On the other hand, by changing the susceptibilities in some predetermined manner to give one or more strongly magnetic products, those differentials can be increased and a more sensitive control realized with much weaker magnets, which require, of course, a smaller expenditure of energy. Weakly magnetic minerals, even of similar composition, seem to show some degree of variability in strong fields, and a similar effect might also be encountered through variations in the roasting treatment. Such a point, of course, would be likely to need consideration only at a further stage in the development, but I am raising it because I should like some information. If it did occur, that might upset separation into the various fractions, and be reflected in non-uniformity of composition of some intermediate products, such as sinter, or even in the actual furnace burden.

Although the magnetic product, as obtained in this process, may have substantially the same iron/oxygen ratio from piece to piece, I take it that the precise composition of a single fragment, in terms of the oxides present, would vary with the temperature and rate of reduction, unless the initial size grading of the material were relatively narrow. I should like to ask the author whether he finds that certain size fractions, if he takes them before the final crushing, do in fact show optimum properties after specific processing conditions, and also what phases in addition to the γ ferric oxide he actually found.

Another question relates to sulphur. I think that the Thealby and Wing ores are rather high in sulphur. How are they affected by a preliminary roasting process with a reducing atmosphere ? Sulphur concentration must, of course, be avoided wherever possible. Another point concerns the magnet unit. Is the best separation obtained with the belts running at the same speed, rather than at different speeds ?

As the process stands at present, it appears that the magnetic separator can deal with a much larger quantity of material per hour than the kiln, and therefore could cope with more than one kiln.

The microsections shown in Figs. 1 and 2 very clearly indicate the difference between the Northants and

Frodingham beds, both in the structure of the ooliths and the matrix surrounding them. It seems certain that very different processes will be required to free the iron-rich material in each case. I am sure that we shall look forward with great interest to any further contribution which Dr. Reeve and his colleagues may make on this interesting subject.

Dr. **T. P. Colclough,** C.B.E. (Iron and Steel Board)* : Traditionally, the economic use of British ores for the manufacture of pig iron has been based on a plentiful supply of relatively cheap coal and the low cost of winning the ore by open-cast workings. Today these conditions are changing rapidly. The depletion of the outcrop-ore reserves, and the increasing depth of overburden, has increased the cost of ore and there will be further increases as underground mining has to be adopted. More important still, the increases in the prices of coal and coke have a marked bearing on the use of home ores. As a result of these trends, it becomes more and more important to attain the maximum efficiency in coke use.

It is now about fifteen years since the first tests were made on blast-furnace operation with crushed and graded ores. The preliminary tests have been fully confirmed, and, today, it is recognized as fundamental that the home ores should be prepared in such a manner as to give a burden uniform and regular in size and composition. This has led to a marked economy in coke consumption and increased production, and it is probable that recent installations are approaching the limit to which this principle can be economically applied.

In another direction, the burdening of furnaces to yield slags of relatively low lime/silica ratio has given a resulting lower slag volume and coke consumption. This method, also, has definite limitations.

So far, however, no steps on the practical scale have been taken, in this country, to effect economies by the upgrading of the ore. This paper presents the first detailed examination of home ores for the purpose of removing part of the gangue or impurities in the ore before charging into the blast-furnace. This subject and the method of treatment were dealt with in a paper that I presented to the Institute in 1944.† It is of special importance that certain types of British ore have been proved to respond to the treatment outlined in that paper.

In the description of the experiments, one important factor is not dealt with. It is clear that the simplest type of ore to be beneficiated will be the well-weathered outcrop ores or limy ores, in which the iron oxide is not associated intimately with lime or silica, either chemically, physically, or crystallographically. In such cases, the temperature of the roasting operation will be that at which the iron oxide is converted most readily to the magnetic condition. On the other hand, where the iron oxide is in combination with other oxides, or forms part of a crystalline complex, then, before the iron oxide can be changed into the magnetic state, the temperature must be such as to secure the breakdown of the chemical compound or crystalline form. This temperature will vary according to the character of the ore and each type of ore will require individual examination to determine the optimum temperature.

Attention should also be drawn to the influence of the rate of cooling of the roasted ore on the magnetic properties of the iron oxide.

In addition to the ores of North and South Lincolnshire so far examined, it will probably be found that both the outcrop and limy Oxfordshire ores will also repay investigation. These ores are won at relatively low cost, and if proved amenable to magnetic roasting, a wide field of increased useful application would be established for these vast resources.

Mr. **J. M. Ridgion** (British Iron and Steel Research Association) : The problem opened up by the author is a very important one and, particularly in relation to the siliceous Northants deposits, one of the most difficult in the world. In the U.S.A., "low grade" ores usually turn out to be quite reasonable by our standards, but some time ago I visited two concentration plants there, which deal with material of really low iron content.

The newly opened deposits in Texas appear to contain about 15–18% of iron, but a very simple washing technique, involving crushing to a little less than 1 in., is sufficient to give a concentrate with 42% of iron, which does not even require to be sintered. Being intrigued by the author's method of expressing the concentration efficiency factor, I used the available data on the Texas ore and obtained a factor of about 200.

There are certain other ores in the U.S.A., in the Birmingham district, which are a much more difficult proposition. Some of the Alabama ores are treated by tabling, and there, one of the main difficulties is to get rid of the silica without getting rid of too much of the lime. The actual separation of fairly rich concentrate is not very difficult, but, if they do not wish to lose all the lime, the layout of the equipment becomes rather complicated.

In this country, of course, we have this problem of compounds of iron containing silica and alumina, where the iron occurs in the form of a chemical compound. In order to achieve separation, in this case, it is fairly clear that we may have to go to much smaller particle sizes than have ever yet been handled in any ore concentration proposition. The actual liberation of the iron oxide from such compounds, and rendering it magnetic is, I think, fairly simple, but the problem is then a physical one of separating the almost molecular particles of iron oxide.

In connection with Table III, I believe that in the Frodingham ore there are significant amounts of chamosite, and that this becomes more serious with the unweathered ores. It is therefore interesting to compare the two groups of data in Table III, taking tests 32 and 35, which are weathered ores that one would expect to be particularly amenable to this process, and the other three, which are referred to as bedded ores, which I presume to be the general furnace mixture of the time. It is rather surprising that the concentration factor is better with the bedded ores than with the specifically weathered types.

I wonder whether tests 17 and 24 are actually the same initial sample of ore. They appear to be. Perhaps the author would comment on the difference in performance of the concentration process in the two cases. Test 24 has a higher concentration factor and a higher iron yield, and I wonder whether the difference (for example, the setting of the magnetic concentrator) which accounted for that change was known.

Mr. **I. S. Scott-Maxwell** (British Iron and Steel Federation) : I should like to raise one point in connection with the magnetic separator. I notice the author says it is operated by D.C. I remember when discussing the Lurgi plant at Watenstedt with the Germans, that they had a different type of separator, a drum type, with a series of vertical drums. These were originally designed for D.C., but a considerable improvement in separation was obtained when single-phase rectified A.C. was used rather than D.C. This means that one cuts off the bottom half of the sine wave, and one gets a series of positive impulses,

* Read in Dr. Colclough's absence by the Secretary.

† *Journal of The Iron and Steel Institute*, 1944, No. II, pp. 359P–374P.

3000/min., which is supposed to give a much greater agitation of the particles and hence a better separation. Unfortunately, I cannot quote any figures to substantiate this suggestion, but I should be interested to know whether Dr. Reeve has made any experiments of this nature.

CORRESPONDENCE

Dr. **J. Taylor** (The Royal Technical College, Glasgow) wrote : I wish to draw attention to one very important aspect of concentration not touched on by Dr. Reeve. The finely crushed concentrate must be agglomerated before charging into the furnace, which, at the present day, probably means sintering. In addition to the extra expense, sintering raises the very important question of reducibility. A saving grace of the lean Midland ores, and one that enables such lean burdens to be smelted economically, is the high reducibility. Sinter made from concentrates would certainly be of much lower reducibility. We must be careful that what is gained in the swings of decreased slag volume is not lost on the roundabouts of inferior reducibility. The problem does not arise when concentrating natural magnetites, which are initially of poor reducibility, but it is certainly important for our home ores.

Dr. Reeve is using the Luyken's magnetic-roasting method by which the iron oxide is first partially reduced and then reoxidized to the ferromagnetic $\gamma\ Fe_2O_3$. As Dr. Reeve has not yet used the X-ray spectograph to examine his product, some laboratory data on $\gamma\ Fe_2O_3$ may be of interest. Briefly, when the normal α form is reduced, it goes to a spinel, usually referred to as Fe_3O_4, although the same crystal structure obtains over a considerable oxygen range. On oxidation at comparatively low temperatures, $\gamma\ Fe_2O_3$ with the same structure as the spinel is formed. The $\gamma\ Fe_2O_3$ is, however, metastable, and, at about 350–400° C., quickly reverts to the non-magnetic form. Re-oxidation should, therefore, either be carried out below this temperature, or the oxidized material be rapidly cooled. This must react on the temperature in the reduction zone of the kiln. The rate of reduction increases with temperature, but if this temperature gets too high there is the danger that α and not $\gamma\ Fe_2O_3$ will form on re-oxidation. It would, I think, be very useful to keep a check on the $\alpha\ Fe_2O_3$ in the product by means of the X-ray spectrograph.

Dr. **W. Davies** (The United Steel Companies, Ltd., Rotherham) wrote : Though the German work on magnetic concentration is fairly well known, it may be of interest to call attention to certain points of difference between that work and the work of Dr. Reeve. At first the Germans applied the technique to siliceous ores in which almost all the iron is present as soft limonite ooliths set in a soft clayey matrix containing little or no iron. The process was intended to harden as well as to magnetize the ooliths, so that when the roasted ore was hammer-milled, the ooliths would shell out like peas from a pod. Though Dr. Reeve has applied the technique to the siliceous Northants ironstone, I do not think he expected much success there, for the matrix, being composed of siderite ($FeCO_3$), contains as much iron as the ooliths, composed largely of chamosite with some limonite. Instead of separating iron-bearing ooliths from the iron-poor matrix, he would have to grind finer than 5μ to free the magnetic oxide and develop a satisfactory method of separating dusts magnetically.

The Frodingham Ironstone type D, which is composed of limonite ooliths in a matrix of calcite, presents the nearest parallel to the German work. Even so, the matrix is a hard limestone instead of a soft clay and it would be expected that the ooliths would not separate readily. However, the roasting renders the matrix fairly friable, despite the fact that there is little or no decomposition of the calcite at the roasting temperature. Theoretically, Dr. Reeve has not reached the limit of concentration, for the ooliths contain between 5 and 10% of gangue, hence we may hope that, eventually, he will attain a concentrate with 55–60% of Fe—the theoretical maximum. Already his data go far to justify the application of magnetizing roasting to the Frodingham Ironstone on a commercial scale. A little more progress will make it essential.

Mr. **G. A. V. Russell** (Messrs. Dorman, Long and Co., Ltd., Middlesbrough) wrote : Compared with pre-war conditions, the disproportionate increase in coke prices, accompanied by a deterioration in quality, has profoundly altered the economic balance of iron manufacture from our domestic lean ores. The possibility of beneficiating these materials is, therefore, much more worth exploring. For such reasons those whose blast-furnace operation is based wholly or partially on these ores will welcome Dr. Reeve's account of his work on magnetic roasting of Frodingham and Northants ironstones. The method employed appears to resemble the so-called Lurgi process which was to have been worked in a big way at Salzgitter with the deep-mined ores of that region.

In Table II the size of the ore feed is given as $\frac{3}{8}$ in. It is presumed that this is a maximum and that, with it, there would be a considerable proportion of finer material. Unless the ore suffers considerable size degradation in roasting, $\frac{3}{8}$-in. pieces would appear too large to expose a sufficient proportion of the ooliths for efficient recovery.

It would be valuable, in this connection, to learn the author's views as to the maximum size at which a reasonable degree of beneficiation is obtainable, and how the ore should be crushed or otherwise reduced to this size. This is important, because, from the economic point of view, the cost of fine grinding, if carried out by such appliances as ball or rod mills in series with one- or two-stage crushing, is an important item on the debit side. It must be remembered that, after separation, the concentrates require sintering or otherwise agglomerating before they can be utilized in the blast-furnace.

In the case of the Frodingham ores, it is perhaps unfortunate that the enrichment of the concentrate is chiefly effected by a reduction in CaO content, and not by the SiO_2 and Al_2O_3, so that the percentage of the richer Northants ore that can be carried in a self-fluxing burden, will be reduced.

Mr. **R. J. M. Dixie** (The United Steel Companies, Ltd., Grantham) wrote : I congratulate Dr. Reeve on his most interesting work on magnetic concentration. The results obtained on certain of the Frodingham ores are most encouraging.

During the presentation of the paper, a slide of Frodingham Ironstone type D was shown and, in the discussion following, very little attention was given to the other types (A, B, C) of ore present in the ore bed. Of these other ironstones, type B, a chamosite–siderite mudstone, does not occur in sufficient quantities to be of any great practical interest. Types A and C, consisting of limonite ooliths set in a matrix of siderite and chamosite, however, comprise a considerable proportion of the total ore body. In general terms, the ore in the Frodingham bed, as worked at present, consists of 30–40% type D and 60–70% types A and C. The type D ore is relatively hard, while the types A and C ore are relatively soft and friable, hence mining operations tend to produce lumps of type D ore and fines of types A and C ores, *i.e.*, the chamosite-rich types of ore.

During the bedding operations at the Appleby-Frodingham Steel Co. works the fines are screened out and the beds made up of lump ores, and this operation tends to segregate the limy type D ores on the beds and

the chamosite-rich ore in the fines ; consequently, tests 17–27 were carried out with an ore containing a higher proportion of calcite, and a lower proportion of chamosite and siderite, than the normal run-of-mine ore.

The highest iron recoveries were obtained from tests 32 and 35 from Winn's No. 3 face. The type C ore from this face is rather unusual in that it has an insoluble content practically double that of similar types from other faces. This higher insoluble content is due, in part, to the presence of silica as quartz, and it is suggested that the slightly higher iron recovery obtained from this ore was due to the presence of silica as quartz instead of silica combined with iron as chamosite.

Dr. **J. H. Taylor** (Geological Survey, London) wrote : Dr. Reeve's paper is a most valuable and timely one, and he is to be congratulated upon providing the first published account of large scale beneficiation trials on British bedded ores. There seems little doubt that the problem of concentrating these ores will become increasingly urgent in the future, and it is worth while considering the possibilities and limitations of the method described.

The improvement in grade of the Frodingham ores tested by Dr. Reeve is due almost entirely to the removal of calcite. The type D variety of ore illustrated in the paper, and consisting essentially of limonite ooliths in a calcite groundmass, is obviously particularly well suited for concentration in this way and it would be interesting to know how great a proportion it comprised of the bedded mixtures of Frodingham ore used for tests 17–27. Since the form of beneficiation employed is capable of producing a more nearly self-fluxing burden from the Frodingham ore, its use on the large scale would presumably result in a reduced demand for Northampton Sand ore for blending with the more limy material. The process appears to be equally applicable to the marlstone ores of south Lincolnshire, Leicestershire, and Oxfordshire, which also contain a high proportion of calcite, and are commonly blended with Northampton Sand ore. Unless, therefore, some complementary process for upgrading the latter were devised, the effect of extensive beneficiation on these lines might well be to unbalance the economy of companies operating both in the Northampton Sand field and in the Frodingham field or one of the marlstone fields.

No removal of silica or alumina was effected in Dr. Reeve's experiments and it is, therefore, not surprising that tests on Northampton Sand ore proved unsatisfactory. Calcareous varieties of this ore are largely restricted to the basal portion of the bed (the lower siderite mudstone–limestone group of the Geological Survey and the ' bastard stone ' of the ironstone companies) which commonly carries 20%, or less, of iron, together with high silica, and is never worked. Since the silica in this part of the ironstone is largely present as free quartz grains, it seems reasonable to expect that magnetic concentration would effect an appreciable improvement through removal of silica as well as calcite. However, exploitation of the bastard stone would involve problems similar to those of the ' remining ' of the basal portion of the Frodingham ore, and it is unlikely to be regarded as a practicable proposition in the foreseeable future.

As far as the remaining lithological types of the Northampton Sand ore are concerned, there appear to be two broad categories. Certain beds, not appreciably calcareous, contain much of their silica as free quartz. This applies to the sandy siderite mudstones, which are present at the top of the formation in both the northern and southern portions of the field, and also to certain highly siliceous ores occurring along the eastern and western margins. Such material is neglected at the present day, but with appreciable removal of silica it might be brought well within the limit of workability. Magnetic concentration or flotation (both of which have been successfully employed on similar foreign ores), or even straightforward washing, might prove successful for dealing with these ironstones.

A great part of the Northampton Sand ore, however, carries its silica, not as free quartz, but, in combination with alumina and iron, either as the mineral chamosite in the fresh ore, or as intimately associated clay and ferric oxide in the weathered material. Calcite is generally not present in sufficient quantity for any useful degree of concentration to be effected by its removal. Methods of treating such ore, by chemical extraction or by direct reduction, though technically possible, are uneconomic at present. The adaptation of beneficiation processes to material of this type, which comprises a very substantial part of our home ore reserves, is the most difficult, but, unfortunately, also the most pressing of the ore-dressing problems presented by the British bedded ironstones.

AUTHOR'S REPLY

Dr. **L. Reeve** (in reply) : I must thank all those who have joined in the discussion of this paper. The interest which it has aroused confirms the importance with which the subject of concentration of home ores is now regarded. Several speakers have mentioned the need for developing concentration processes to treat, if possible, the siliceous Northamptonshire ores, but as I have indicated in the paper, there are fundamental differences of microstructure which make this difficult to achieve, and it is unlikely that the method described in the paper will be applicable to ores in which either the matrix or the ooliths contain most of their iron, in the combined form, as chamosite. Some of the Northamptonshire ores, which contain free quartz, may be more suitable, whilst, as pointed out by Dr. Colclough, the limy Oxfordshire ores should be amenable to some degree of concentration. Actually, a few laboratory tests have been carried out on a sample of the latter ore, which resulted in an appreciable degree of concentration.

The degree of variability of the results obtained on the kiln has been mentioned by several speakers. The figures reported in Table III for tests 17–27 may be regarded as fairly representative of the variability which may be expected in practice. In reply to Mr. Ridgion, these results were obtained on a single consignment of local (mixed) ore. On looking up the records for these tests, it appears that the slightly poorer results obtained in test 17 were most probably due to a slight fall in temperature, which was deliberately introduced into this test. The figure was 700° C., instead of 740° and 760° C., for tests 24 and 27, respectively.

The question of the influence of weathered ores, referred to by Mr. Ridgion and Dr. Colclough, though not fully dealt with in the paper, is receiving a fair amount of attention. In this connection, Mr. Ridgion's question regarding tests 32 and 35, in Table III, should be specially mentioned, as I am afraid I have been responsible for unwittingly misleading him by stating that these ores were ' slightly weathered.' This is correct, but I should have indicated that the ores in tests 17–27 were, on the average, more weathered than those in tests 32 and 35, the latter ores containing rather more siderite and chamosite than the former. As Mr. Ridgion points out, the concentration factors for the bedded ores 17–27 are higher than for 32 and 35, and the explanation I have given accounts for this difference. Several other tests have been carried out on local ores of the A and C types containing appreciable quantities of chamosite. Though this is not the place to go into

details, it can be stated that whilst the degree of concentration is lower than in ores which are richer in type D, appreciable concentration, owing to the removal of calcite into the tailings, is still achieved.

Dr. Saunders raised the question of variability in relation to ore size. The maximum size of material charged to the kiln is normally $\frac{5}{8}$ in., but the feed also contains about 35% under $\frac{1}{16}$ in. Much of the larger material passes through the kiln unchanged in size, and it is possible to compare the degree of concentration resulting from both coarse and fine. The difference is not as great as might be expected. Examination of a cross-section of these large pieces shows a black centre of Fe_3O_4, surrounded, to a greater or lesser degree, by a reddish coloured oxidized skin of Fe_2O_3. It is probable that, whilst there is sufficient time for reduction to proceed to the centre of these large lumps, there is not enough time for oxidation to be completed in the cooling zone at the temperatures available. Nevertheless, the difference in magnetic properties between centre and outside is not sufficient to affect the concentration results to any serious extent. More detailed examination of size effects is proceeding.

Dr. Saunders has enquired, what happens to sulphur during the concentration process ? I am afraid that I cannot answer this question, simply because the problem is much too complex to discuss, short of another paper. We have done a good deal of work on the subject, and all that I can say, at this stage, is that, by the process described in the paper, there is a slight sulphur improvement in the concentrate, in the sense that the sulphur per unit of iron is somewhat lower in the concentrate than in the tailings, but the degree of desulphurization achieved in this way is not very great. On the other hand, by altering the kiln temperature and atmosphere in suitably controlled zones, it is possible to remove a very large part of the sulphur from the concentrate. I hope to give more details at a later date.

Some questions have been raised concerning the control of the magnetic separator and its output. The control of the weight and richness of the concentrate is achieved, either by altering the current in the magnets, or by altering the distance between the belts. Alteration of the belt speeds controls the output of the equipment, which is finally limited by the output of the fine crusher, which is 5 cwt./hr. maximum, whereas the kiln, though designed for working at less than this figure, is actually capable of producing up to 9 cwt./hr. The magnets are supplied with rectified 50-cycle A.C. The influence of high-frequency A.C. has not been investigated. According to information from German sources, although some improvement in results can be obtained by changes in the magnetic system, these are relatively slight compared with the effects of changes in the roasting procedure. However, should the process be put on a production basis, where every improvement in yield per cent will become important, more attention will be paid to the magnetic separators.

REPLY TO CORRESPONDENCE

Dr. **L. Reeve** wrote: Many of the questions in the written contributions to the discussion have already been dealt with in the verbal discussion, but there are a few additional points to be considered. The one raised by Dr. J. Taylor (Royal Technical College, Glasgow), concerning the relative reducibility of the concentrate and the sinter produced from it, has already been discussed on another occasion.* Sinter produced from these ores, whether concentrated or not, is admittedly less reducible than the original ore from which it is made. Nevertheless, the general trend at present is to sacrifice the degree of reducibility to some extent, in order to improve the strength of the sinter, and such considerations will no doubt apply to sinter produced from concentrated ores. Our present information does not support the view that the main advantages of increased output and reduced coke consumption will be lost in sintering the concentrate.

With regard to Dr. Taylor's point concerning the reversion of Fe_2O_3 to the non-magnetic form, and his suggestion that re-oxidation should be carried out below 350–450° C., it would appear that under the fairly quick cooling conditions attained in the kiln, maximum roasting temperatures can be as high as 790° C., without seriously reducing the iron content of the concentrate. There is reason to believe that oxidation occurs at temperatures below the recorded maximum. Nevertheless, even under laboratory conditions, we find that it is possible to re-oxidize, for an appreciable time, at temperatures up to about 600° C., without seriously reducing the iron recovery. Thus, oxidizing in air, at 600° C., for 10 min., showed no loss in iron recovery, whilst oxidizing for 30 min. produced a loss of only 1·5%.

I must thank Dr. W. Davies for his encouraging remarks. In the case of some of the fully weathered Thealby ores, rich in limonite and low in chamosite, we have obtained concentrates containing as much as 50% of iron, but I think he will agree that for the Lincolnshire ores generally, particularly those of types A and C, we are unlikely to obtain the 55–60% of iron in the concentrate, which he mentions as theoretically possible. His discussion of the siliceous German ores is worthy of careful study, as the difference in structure between these and the siliceous Northants ores is of considerable fundamental importance.

The points raised by Mr. G. A. V. Russell regarding optimum size of ore are partly covered in my reply to Dr. Saunder's question. He will no doubt recall that, although the feed to the kiln is $\frac{5}{8}$ in. max., this material after magnetic roasting is crushed to $-\frac{1}{32}$ in. in the hammer mill (U) above the magnetic separator. There does not appear to be any need for fine grinding in ball or rod mills which, I agree, would add considerably to the cost. Whilst it is true, as Mr. Russell states, that the effect of concentrating the Frodingham ores will be to reduce the percentage of the richer Northants ore which can be carried in a self-fluxing burden, this does not alter the fact that the present self-fluxing burden contains a maximum of only 27–29% of iron, whilst the concentrated burden would contain over 40% of iron after sintering.

The relative degree of concentration achieved in types A and C ores, compared with type D, raised by Mr. Dixie, I have already mentioned. Mr. Dixie is correct in stating that concentration of natural fines from the Lincolnshire ores, compared with that of crushed fines, tends to give somewhat poorer results, because of the larger amount of types A and C carried in the former. Calcite, however, is still transferred to the tailings to an appreciable extent, even in this case.

Dr. J. H. Taylor's summary of the types of ores present in the Northamptonshire beds is of considerable value, and confirms similar points raised in the verbal discussion, particularly the greater possibility of concentrating the limy Northamptonshire and Oxfordshire ores. I agree that the development of suitable concentration processes to treat Northants ores containing combined silica is the most pressing of the ore-dressing problems presented by British ores.

* H. L. Saunders and H. J. Tress : *Journal of The Iron and Steel Institute*, 1945, No. 11, pp. 315P–316P.

Discussion on the Paper—

THE WORK AND ORGANIZATION OF A STATISTICAL DEPARTMENT IN HEAVY INDUSTRY, WITH PARTICULAR REFERENCE TO THE STEEL INDUSTRY,*

by A. W. Swan

Mr. **A. W. Swan** (The United Steel Companies, Ltd., Sheffield) introduced his paper.

Mr. **W. J. Jennett** (General Electric Co., Ltd., Wembley, Middlesex): I am sure that the meeting will discuss more easily the applied aspects of the paper than the purely statistical ones. Nevertheless, I am convinced that certain principles require emphasis for a proper appreciation of the value of statistical methods, and I may be of some service if I devote my remarks to them.

The author has dealt at length with what he calls theory, presenting the steps simply and plainly, but I would prefer to think of this as a combination of principles and technique. The technique is expressed by formulae which are not difficult to grasp; the principles are less tangible and require a different mode of thought. When using statistical methods it is necessary to think in terms of groups and probabilities, rather than in simple entities and certainties. Mr. Swan expresses this principle in simple language when he says that the central theme of the work is that small numbers are being used to tell us something of big numbers. It should be noted that in this sense he means small numbers of things are being used to estimate the properties of *groups* of large numbers of things. The property of the individual will no longer be identified in the estimates of the large numbers. The properties will be identified precisely of the group or collective, leaving estimated properties of individuals to be stated in terms of probabilities that they lie within a certain range of values.

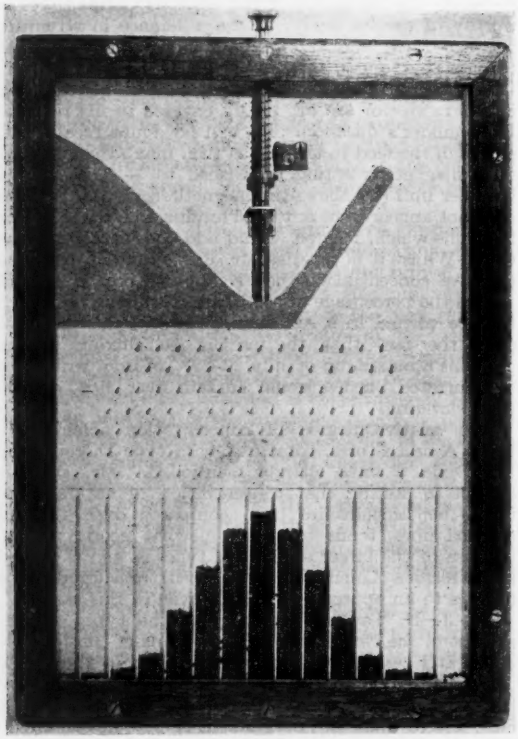


Fig. A—Galton model for demonstrating normal distribution resulting from chance disturbances

This fundamental concept can be demonstrated by means of a small model (illustrated in Fig. A) based on an apparatus devised by Sir Francis Galton. In this model a large number of small seeds are allowed to fall from a hopper into vertical compartments. The position of the compartments on the horizontal scale may be likened to the markings on a target or the value of some property or quality of a manufactured article. The object is to achieve the centre of the target with each shot but, as in any task, even though our aim may be correct, the seeds, as they fall, meet uncontrolled disturbances in the shape of rows of pins from which they bounce by chance to left or right. The result is that the seeds are distributed about the centre of the target, a maximum number being at the centre of the target with fewer occurring as the distance from the centre increases. On repeating the process a number of times the same distribution is obtained on each occasion, even though particular seeds will arrive at different positions. This is an example of a large number of things having individually different properties whilst collectively the properties are constant, just as in fact the process (in this case the model) is a constant thing.

Numerically, the properties of such a distribution can be expressed by two values, one of the position of its centre and one of its spread, and if these had been calculated after only a few seeds had fallen through they would have provided an estimate, based on small numbers, of the properties of the large numbers which could be obtained by continuing to operate the process. It will be seen that we are speaking more and more of processes and less of products. It is not that we are not interested in the property of an individual mould, say, as such, but that in studying the process which provides the moulds we must think of the collective of moulds it can produce.

Considering now a quite different aspect, the author refers to the importance of human factors. The practical statistician cannot work in isolation, and although it is of importance that he should have a sound knowledge of the technique of statistical methods, it is even more important that he should acquire a sense of proportion regarding the part which statistics plays in solving practical problems. The figures which constitute statistical data may be without feeling, but it should be realized that they come not merely from steel that is steel but from the men who produce it.

One characteristic which I regard as highly desirable in those engaged in this kind of work is that they should be enthusiastic enough to persist in the face of all sorts of difficulties, and particularly in the face of opposition from the sceptic. There are always people who say about any new method: "It is all right for this or that industry but not for mine." The thing to do is to try it. If it is recognized that the operation of processes demands experience and detailed knowledge, then additional knowledge of statistical method, intelligently applied, can enhance the value of industrial effort.

* *Journal of The Iron and Steel Institute*, 1948, vol. 160, Sept., pp. 1–20.

Mr. **N. H. Bacon** (Messrs. Steel, Peech and Tozer) : The author has shown very clearly that this modern science of statistics—because it really is modern—can be applied to steelworks problems with a very great measure of success.

The value of this paper to the steelworks man is largely confined to the second half of it, from page 14 onwards, because in the earlier part some of the examples chosen to illustrate the statistical method are a little unfortunate. For example, on page 9 the steelmaker who reads this paper finds that it is proved that the variation in the carbon results of 0·70–0·75% carbon steels is greater than in 0·08–0·12% carbon steels. A steelmaker who may not be very sympathetic towards statistics will say : " Anybody could tell you that, without any statistical work." He could also say that the proportion of 0·70–0·75% carbon steel casts likely to be outside the specification can be determined by the simplest arithmetic.

Again, on page 11 the author speaks of comparing the efficiency of operation of three open-hearth furnaces in attaining the mid-specification carbon value of 0·73%, and then goes on to what the ordinary steelmaker would regard as quite elaborate calculations ; but the steelmaker might doubt the common sense of the statistician who attempted to deduce the performance of three open-hearth furnaces by comparing the results of three casts taken at random from each furnace.

Exception might also be taken by the mill manager to such a statement as that on page 13, where the author talks of the effect of the percentage of stainless-steel ingots on the rate of output, and says that the shift foreman cannot now stretch this excuse of a large proportion of stainless-steel ingots beyond the limits which have been found following the statistical analysis of the results. The mill manager will rightly say, " Well, he could not have done it before ; he could not come to me and say ' I rolled only 19 tons/hr. because I had 100% stainless ingots ! ' because I should say to him ' How is it that you have previously rolled 29 tons/hr. with 100% stainless ingots ? ' " as shown in Fig. 11. I think that the statistician, having worked out his sums, has to be extremely careful about the way in which he puts them across to the man in the shop.

These remarks are not intended as serious criticisms of this most valuable paper, but I mention them because I think that the practical man to whom these methods are novel may be put off a little by such examples as are given in the first part of this paper, and may not continue as far as the second part, which proves most conclusively that this method is most useful. I can myself from long experience heartily commend it to the consideration of those engaged in the steel industry.

Mr. **D. H. Ward** (Appleby-Frodingham Steel Company) : There are certain duties of a works statistician which a department like the author's will not meet so often. These include keeping track of routine records which are likely to be used in the future, and understanding their weak points ; moreover, there are numbers of works experiments, often small-scale experiments, where the works statistician can give advice on the design, and there are many minor jobs which ought to be done by statistical methods instead of by hit-and-miss methods. A large part of the duty of a works statistician is to report to the management on the significance of results already reported in one form or another by other departments. This involves simple applications of common sense as well as of statistics, but the statistician also has to watch out for theoretical snags. For example, when dealing with surface defects, as in the author's Bessemer rail problem, it is necessary to watch out in case the rails from the same cast are associated. This is a difficulty which occurs not only with rails but with plates and sections. If what I call a ' cast defect ' is being studied, then either the whole cast will be good, or the whole cast will be bad. The unit becomes the cast and not the individual rail, and the value of χ^2 is greatly altered.

Another task of the works statistician is to get people to think statistically, as Mr. Jennett has emphasized. One example is in the case of sampling. A method of sampling may be very precise, but it may be biased ; in other words it gives a result which is too high or too low always by the same amount. Again, a sample may be unbiased, but not precise ; its average value is correct, but individual figures vary widely from the true figure, being sometimes above and sometimes below, at random. At Appleby-Frodingham statistical methods have been used to study ore and coke sampling methods, and to judge which sampling methods give the best results, both on a basis of lack of bias and on a basis of precision.

Another example of statistical thinking is that one gets into the habit of basing hypotheses on recorded facts, instead of using the recorded facts to illustrate an idea which one had before looking at the figures. That is not statistics but common sense, but unless you go through the rigorous routine of thinking in a statistical way, you may be fooling yourself.

A third way in which people can help the statistician by thinking statistically, is that they should consult him when an experiment is being planned, and not after it has started. He can then advise on the arrangement of the experiment and on the best form of recording the data, so avoiding possible wasted effort and worthless results. That is emphasized in several of the author's examples.

Finally, I should like to make a brief comment on the author's requirements for a practical statistician. A statistician may well be an engineer or a metallurgist or a chemist, but in order to make use of the new techniques which have been discovered, and to use correctly the well-established techniques, he nearly always requires training and help from a qualified statistician, or else he may make some very bad mistakes, which will kill the confidence of the management in statistical methods.

Mr. **T. Sanderson** (Workington Iron and Steel Company) : One of the practical examples given in the paper, concerning the effect of coke quality and other variables on blast-furnace performance, was carried out at the works with which I am associated, and perhaps members may like to hear of the circumstances which made us employ statistical analysis in this case. The present-day cost and scarcity of coke bring into sharp focus the need to reduce coke consumption, and the question which we asked was : " What are the most important factors affecting coke consumption, and by how much do they affect it ? " The qualitative effects were known with a fair degree of certainty, but the quantitative effects were purely a matter of conjecture. From the answer to the question, the management would be able to see the best line to pursue to reduce coke consumption, and also to determine the economics of any improvement scheme which might be contemplated.

It had long been known that coke quality had a marked effect. Other experience agrees with this, but it is necessary to be extremely hesitant before using quantitative data derived from other plants. Probably the best way is by means of a planned experiment, operating the furnace for, say, 2 to 4 weeks with a given coke, then changing over to a better coke for the same period, and then reverting to the original coke, keeping constant as many of the other factors as possible. Such an

experiment can be carried out in a period of 6 to 12 weeks and gives fairly quick results, but it can be done only at a large works where many different qualities of coke are available.

At our own works, a fairly small integrated works, where all the coke is produced on site, and the day-to-day variation in coke quality is not very marked, such a technique was denied us. Also, being users of foreign ores, burden changes are at present so frequent that the conditions for the test could not be met. It was for this reason that statistical analysis was employed. It might be said that we were comparatively favoured by the uniformity of the coke, and for production purposes that is so ; but for purposes of examination and experiment, variation is required, and the greater the fluctuation the better.

It cannot be said that the examination revealed factors that were hitherto unknown or unsuspected ; but it did give quantitative values of the type that if the $-\frac{1}{2}$-in. shatter was decreased by $x\%$, then the coke consumption would be decreased by $y\%$. The quantitative values found are valid only over the range of data examined and apply only under the conditions appertaining during the period of the test, which was about 74 weeks. Care must be taken in extrapolating outside these ranges, particularly if it is thought that some of the relationships may be curvilinear at the extremes ; for instance, the effect of the $-\frac{1}{2}$-in. shatter index might be curvilinear. A rise of 1%, from 4% to 5%, in the $-\frac{1}{2}$-in. index might affect the furnace performance more than a rise from 3% to 4%. Similarly, if the conditions are radically changed so that, for instance, the coke consumption is reduced from 18 cwt./ton to 16 cwt./ton, then at the lower coke consumption the coke quality is probably more critical.

These limitations do not detract from the value of the work. The statistical technique has given these quantitative values and it has enabled the statistical department to compile a blast-furnace index which is useful to higher management, and which will be very useful in further experimental and research work.

Formulae have often been proposed for comparing the performances of furnaces at different plants, but this is extremely difficult. It is known that coke consumptions of two furnaces running on fairly similar cokes and ores and producing similar grades of iron, can vary considerably. Perhaps the approach should be to determine the quantitative effects on a furnace at each works and then to compare these between works.

Mr. **H. Herne** (British Iron and Steel Research Association) : The British Iron and Steel Research Association has two sections which are particularly concerned with statistical methods, an operational research section and a mathematical section. The mathematical section works largely as computers for other sections of the Association, analysing their data and making such statistical tests as are requested. It has, therefore, a rather restricted range of interest compared with the whole field of applied statistics in industry.

There seem to be three main divisions of this whole field. Firstly, there is the presentation of a synoptic view to management of the operating conditions of a plant and the general running of a production process. Secondly, there is the control of a satisfactory process —what is broadly called ' quality control'. Thirdly, there is the analysis of experiments designed to improve processes. It is with this third aspect that the mathematical section is most directly concerned. This branch further divides into two : (1) Operational research, dealing with large-scale changes in method and the resultant improvements in process ; and (2) the analysis of controlled research experiments—including what the author has called field trials—where perhaps one variable is altered in a routine production process in the hope of deducing the possibilities of improving the routine process.

There appear to be two kinds of field trial to the applied statistician. In the first the trial is planned from the beginning to give a maximum of information with a minimum of effort, whilst in the second the exigencies of the experiment or the lack of planning provide a quantity of figures of far less value. The mathematical section has to deal with this second case quite frequently, and its task is to reduce the figures to a few logical conclusions with a quantitative basis. In presenting the conclusions it is important to keep in mind that the works operator thinks more of his average value and less of the scatter in the actual figures than does the statistician. Besides providing such analyses the section occasionally co-operates with works personnel and with B.I.S.R.A. trials.

The writer agrees wholeheartedly with the author on the importance of psychology in applied statistics. The problem is to combine the mathematical methods with an appreciation of practical problems and difficulties and an ability to mix with co-workers in different fields. In the past, the applied statistician has usually had an academic mathematical training which tended to emphasize the dichotomy of mathematical method and practical difficulty, but there is a growing class of workers from colleges and polytechnics with a general scientific training and an appreciation of immediate statistical method. This training will obviate the author's difficulties in training engineers, for example, as statisticians, and will automatically provide a type of person better suited psychologically to the world of field trials.

Sir **Charles Goodeve**, F.R.S. (Director, British Iron and Steel Research Association) : In this important paper, Mr. Swan shows how the science of applied statistics, which has proved so useful to certain industries in the hands of such pioneers as Pickard and Dudding, can provide benefits to the iron and steel industry. Here we see statistics being applied not only to the scientific research and to the processes of the industry, but to the operations generally. The term ' operational research ' has been used to describe this work and the application of other scientific methods to operational problems.

Dr. **J. H. Chesters** (The United Steel Companies, Ltd.) : I greatly admire statistical work, but at the same time feel considerable sympathy for statisticians. They are always faced with a dilemma. Either the results they obtain are those which were expected, in which case it is suggested that they have not shown anything new, or else they get the opposite result and it is suggested that this is just the odd 1-in-20 case in which the probability technique has gone wrong. Personally, I feel that for many problems the statistical approach is the *only* sound one, but I also believe that the greatest service a statistician can render in industry is to convert other people to the use of statistics. Models, such as the one illustrated by Mr. Jennett (Fig. A) would do more towards conversion than a great deal of talking. My own faith was considerably increased by some periodic juggling with 10 black balls mixed with 90 white balls in an old ball mill.

It is the man in the works who knows where the problems exist and what are the factors that are likely to be involved in them. Furthermore most of the problems can be tackled by the use of histograms, which is an extremely simple technique ; for example, we were able to demonstrate many years ago that criticisms of deliveries of silica bricks to a particular works were quite unfounded, the alleged soft-fired character of the

product being merely a matter of inadequate sampling. The proof lay in the fact that the histogram for 24 bricks from the new works had essentially the same shape and location as that for a whole year's deliveries at another plant.

One technique which the author has not referred to, but which we have found very useful, is the use of arithmetic probability paper. If the normal or Gaussian distribution is plotted in its cumulative form on such paper it comes out as a straight line and, therefore, any non-Gaussian character can be readily detected. If results are plotted on this paper a sloping line is obtained, the slope decreasing with the workability of the product. The average value based on the samples examined can be readily obtained by the intersection of the sloping line with the horizontal 50% line. We have used this method to study ladles and have shown that one brick was appreciably more consistent than another, and in addition that it gave a slightly higher life, a conclusion which would have been dangerous if taken from only a cursory examination of the figures. I should be interested to hear whether Mr. Swan thinks that there is a use for arithmetic probability paper and whether it enables one to note peculiarities that would otherwise tend to have been missed.

AUTHOR'S REPLY

Mr. **Swan** wrote in reply : The only serious criticisms that have been made are very easy to rebut. It has been suggested that the effect of increasing the percentage of stainless-steel ingots on the net rolling rate, and the use of this information to limit excuses for slow rolling and in connection with the analysis of misfit casts, would already have been known to the management and that statistical analysis would not therefore be necessary. This, however, was not so with either inquiry. In both cases, which actually occurred, there was knowledge of an indefinite character (*a*) that the rolling rate decreased as the percentage of stainless ingots increased, and (*b*) that the high-carbon steels were more variable than the low-carbon steels. In neither case, however, was there any reliable numerical information, and in both cases the results were welcomed and used as described.

The other criticism is that the example of analysis of variance is too simple, that the deductions could be drawn from the figures without any statistical analysis. It is quite true that the deductions could be drawn from the figures, but the critic has missed the point that it was very desirable to show the simplest possible example of the method of analysis of variance that could be devised. The real examples that occur in practice are always highly complex and are often difficult to work out, although they are founded on what is, in fact, a comparatively simple basic technique. It would have been frightening to the reader to have presented such examples, and no apology is made for giving an analysis of variance in the very simplest terms.

The general idea in Part II of the paper was to give in a way which it is hoped is reasonably complete and yet not too complex, the principal statistical techniques which are used in heavy industry.

Discussion on the Paper—

THE APPLICATION OF OXYGEN ENRICHMENT TO SIDE-BLOWN-CONVERTER PRACTICE,* *by J. L. Harrison, W. C. Newell, and A. Hartley*

Mr. **F. Cousans** (Messrs. Hadfields, Ltd.) : Few, if any, steel foundries using the side-blown-converter process are really short of steelmaking capacity. Frequently the steel department is regarded as a service unit to the foundry, and is expected to produce the steel as and when required by the foundry. I do not feel that an increased output of steel per hour would be regarded as particularly helpful, but if other advantages were found, such as reduction in total and final cost per ton of finished castings, owing to the higher temperature of steel, the longer life in the ladle, and the greater fluidity of the steel, which in turn resulted in sharper castings and possibly better and sounder castings, better physical properties, and so on, then the industry would be more than grateful for any development which made such an advance possible.

It must be admitted that the plant used by the authors differs somewhat from those usually worked by side-blown-converter operators. The vessels were orginally Stock converters, and have been modified to use cupola-melted metal. They are oval in cross-section and comparatively short, whereas vessels of more recent design are round in cross-section and longer than the Stock vessels. The internal shape is also somewhat different.

In Fig. 4 are recorded the changes in temperature which occur during normal blows with the Catton plant, and on comparing these results with those obtained from other plants of modern design we find that in the Catton vessels the temperature increment is slightly lower, and the blowing loss slightly higher than with more modern vessels. For instance, in one plant, cupola-melted metal, with 3·0% of carbon and 0·8% of silicon, and an initial temperature of 1290° C., gave an average temperature increment of 360° C., with a blowing loss of 8%.

The remainder of the blowing practice used in Leeds could be regarded as similar to that generally followed in side-blown-converter practice in this country, with the possible exception of the range of chemical composition of the final steel. I consider that most operators work to closer limits of chemical composition than those given in the first column of p. 286, in which are recorded data for 89 heats obtained in November, 1947. Mr. Fassotte† has recorded the analyses of 37 heats made on one shift by a side-blown-converter plant. These analyses showed a variation in carbon from 0·21% to 0·24%, and in manganese from 1·42% to 1·72%, and were in fact to closer limits than those of heats made with oxygen-enriched air and recorded in the present paper. It may be argued that the figures given by Mr. Fassotte were obtained under special operating conditions, but many side-blown-converter operators would claim to be able to produce regularly heats of steel to equally close limits.

On p. 286 are recorded the results of gas determinations of the finished steel with 30% and 40% of oxygen in the blast, but no comparable figures are given for the normal blow, so that it is difficult to assess the effect of oxygen-enriched air upon the final gas content of the steel. It would have been helpful in making comparison possible if inclusion counts of normal heats and of oxygen-enriched air-blast heats had been recorded.

* *Journal of The Iron and Steel Institute*, 1948, vol. 159, July, pp. 281–290.

† *Journal of The Iron and Steel Institute*, 1944, No. II, p. 344P

Some makers would claim for their normal heats, of similar chemical composition, mechanical properties as good as those obtained with a total oxygen content of 30%, as recorded in Table VII.

My reason for pointing out these slight differences in the design and operating data between the Catton plant and vessels of more modern design is that they must be taken into account when considering how far the data given in this paper are applicable to oxygen-enriched air trials with vessels of slightly different design, and of different internal shapes.

The normal blow, as recorded in Fig. 4, shows a temperature-increment rate of approximately 30° C./min. during the first 3 min., approximately 50° C./min. during the second 3 min., 17° C./min. during the third 3 min., and approximately 10° C./min. during the rest of the heat.

The authors draw attention to the change in the rate of carbon combustion and of temperature increment which occurs about half-way through the blow, and in explanation suggest that the slag passes through a viscous and sluggish condition so that oxidation is hindered. I have observed this trend in a number of heats, and slag analyses taken during the different periods show :

	SiO_2, %	FeO, %
First 3 min.	37–47	40–45
Second 3 min.	35–40	42–46
Third 3 min.	50–55	30–35
Rest of heat	55–60	25–30

These figures show clearly a marked change in slag composition 6 to 9 min. after putting on the blast. The rate of temperature change during the first 6 min. of a normal blow—30° C./min. for the first 3 min., and 50° C./min. for the second 3 min.—could, in my view, be regarded as generally satisfactory, giving at the end of 6 min. a temperature increment of approximately 240° C.

During the first few minutes of any normal blow large volumes of brown fumes are emitted from the mouth of the vessel, indicating that iron is being oxidized at a rate beyond the capacity of the bath to absorb it, and this free iron oxide is lost and becomes part of the conversion loss. Using oxygen-enriched air blast at this stage, one might reasonably expect this loss to be greater, and, in fact, the authors draw attention to it. On considering the changes in bath composition and temperature using air blast containing 35% of oxygen, as recorded in Fig. 3, it will be seen that after blowing for 4 min. the temperature increment is approximately 275° C., *i.e.*, only 35° C. higher than after blowing for 6 min. under normal conditions. There are slight differences in chemical composition in the original bath, but probably not more than 0·15% of silicon. It is observed that the authors have conducted trials using 30% of oxygen for 4 min., raising the oxygen to 35%.

Have the authors investigated the possibility of using a normal blow for, say, 6 min., thinning the slag at this stage by a heavy glass addition, and then using oxygen-enriched air for the rest of the blow ? This would save the cost of oxygen for 6 min./heat, and if with the use of oxygen during the final period of the blow a temperature increment of, say, 140° C. could be obtained, it should result in a total temperature increment of not less than 400° C., which should be adequate for most steel-foundry purposes. Such a procedure might also shorten the duration of the blow to 10 or 12 min.

The paper, being a technical one, rightly emphasizes the more scientific aspects, but I am also concerned about any possible economic advantages of the process, and it seems to me important to keep the cost of oxygen down to a minimum. Such a modification to the procedure might not only help to reduce the cost of oxygen, but also tend to reduce the conversion or blowing loss.

I consider that the authors have established points 1 and 2 in their conclusions, but feel that similar advantages, not necessarily of the same order, might probably be obtained by modifying the way in which oxygen is used. I am not quite so happy about the third claim, for quite a number of foundries are operating side-blown-converter plants using cupola-melted metal at temperatures down to, say, 1300° C. with reasonably good results, but I agree that higher scrap charges in the cupola and economies in the use of ferrosilicon are made possible. The authors have established their claims 6 and 7 for the Leeds plant, but I am doubtful to what extent these claims could apply to vessels of modern design.

The authors draw attention to the easier control of the end point of the heat, made possible by the use of oxygen-enriched air blast. Does this apply to heats made in a badly worn vessel ? Frequently there are difficulties with ' wild ' heats, particularly when the lining wear has been excessive. If wild heats are easier to finish correctly with oxygen-enriched air, it will be very helpful to the blower.

Mr. **A. H. Catton** (Messrs. Catton and Co., Ltd.) : I am a steel-castings manufacturer, and this work has given my steel foundry an additional tool with which to make steel more quickly than we could before with the plant at our disposal, and which increases the temperature of the steel that we are now making. The increase in temperature has made possible a number of things, namely the light-section work which we could not previously do ; better castings, because with increased temperature and fluidity we can make squarer castings ; and, I am sure, better quality steel.

Mr. **A. G. Hock** (Workington Iron and Steel Co.) : Can the authors give the analyses of some of the slags obtained, either at various stages, or at the end of the blow ? I ask this because of my association with a company which manufactures steel by the older process of blowing air through tuyeres set in the bottom of the converter. Our own problems are quite different in many ways, but fundamentally there is something in common with those of Messrs. Catton and Co. As a result of the work reported in this paper, and with the co-operation of the British Oxygen Company, we have made a few experiments in blowing oxygen-enriched air through the converter bath.

We have also found that we can increase the temperatures of the steel, if we wish, and it follows that such a procedure might be useful in reducing the consumption of ferrosilicon. Precise ascertainment cannot yet be made, but it can be said that, taking the long view, it is possible that a saving in operating cost may be realized if we bear in mind the likelihood of a lower cost for industrial oxygen produced in bulk.

The greater speed of conversion brought about by oxygen enrichment, raised an interesting question. If a process is shortened it may be thought that there comes a point at which the blower has not quite sufficient time to recover from a position which was abnormal. When adding ferrosilicon to increase the temperature on blows that are too cold, the time of conversion is increased somewhat. When using oxygen the total time is decreased. Although it was felt that this fact might raise a few practical problems, these have been overcome.

The results reported by the authors include data on the gas content of the steel. In a case where steel is being cast in sand it would be of interest to have more results for the gas contents and the inclusion counts.

With reference to the apparent slowing down of the carbon/oxygen reactions, which the authors attribute to changes in viscosity of the slag, a similar effect occurs in the bottom-blown converter. A distinct symptom of the change in viscosity is shown by the increase in

energy required to force the blast through the tuyeres and the bath. The viscosity of the slag varies not only with temperature, but also with the great changes in composition which it undergoes during the blow.

It may be of interest to recall that the initial slag approximates in composition to the eutectic in the FeO/SiO_2 system. As the blast continues to churn metal and slag, the iron-oxide content of the slag diminishes, with the result that acid slags are obtained which contain free solid cristobalite with total silica more than 65%.

Mr. C. McNair (Messrs. Hadfields, Ltd.): I shall confine my remarks chiefly to the conclusions arrived at in the paper. Higher blown-iron temperatures, with the attendant advantages of increased fluidity, appear to be proved by the figures obtained ; since, however, no ferrosilicon is needed during the blow, the only means of controlling the temperature seems to be by the silicon content of the cupola metal. I wonder whether the flexibility of the process has been, to some extent, sacrificed to the temperature.

Are these temperatures in the region of 1800° C. really necessary ? I consider that a ladle temperature of 1650° C. for bottom-stoppered pouring, and of approximately 1700° C. for lip pouring, is sufficient to cast any section. In a slightly different process, we make between 250 and 300 castings in carbon steel from 1-ton stoppered ladles, using high-frequency steel with a furnace temperature in the region of 1630–1650° C. and a ladle temperature of about 1580° C. Are you, with these higher temperatures, getting increased fluidity at the expense of increased fettling ?

Claims are made in the paper for a reduction in the blowing loss by using oxygen-enriched air blast, but these claims are difficult to reconcile with the published matter. Table II gives a loss in normal practice of 8·5%, and Table III, using the reduced blowing rate of 2000 cu. ft./min. and a total of 30% of oxygen, gives a blowing loss of 10·2%, and under similar blowing rates with 35% of oxygen gives a loss of 10·3%. Table IV, containing figures on the effect of increasing the oxygen to 35% after 4 min., gives an average of 7·5%, but included in these data are two figures which are admitted to be too low, and the average for the remaining four figures is 9·5%. The data given for other pressures and enrichments suggest that the blowing loss can become excessive. Losses in converter operations are already a serious economic factor, and an increase of even 1% should not be taken too lightly.

The second point in the authors' conclusions states that a shorter blowing cycle is possible, thus permitting a higher steel output from a given plant ; but surely the speed and output of the plant are controlled not by the blowing cycle, but by the cupola melting speed, and if the blowing time is less than the cupola melting speed the output is independent of the blowing cycle. In my firm the converter plant is a bottom-blown Bessemer with a blowing cycle of 8–10 min. The speed of production is 5 heats delivered to the foundry every 2 hr., with a daily production of 23 heats in 9½ hr. Occasionally we are called on to provide steel for large castings of 20 tons and upwards, and our first step is to double the cupola melting speed by the simple process of working two cupolas. Under these conditions, and by tapping out 4 heats from the cupolas before turning up the first heat, we can blow 8 heats in 80 min.

Item 4 of the conclusions states that since lower silicons and lower metal temperatures can be accepted, a higher scrap charge may be used in the cupola. We have been using 100% scrap charges in the cupolas for the past two years without oxygen-enriched air, although lump ferrosilicon is added to obtain approximately 1% of silicon in the cupola metal. I should like to compare the authors' experiences in this direction with our own. Most of the time we find that 100% scrap can be melted without much difficulty, using a 7/1 metal/coke ratio, but when light scrap coincides with poor quality coke we usually find trouble, and I wonder what trouble has been found at Messrs. Catton and Co. under similar conditions.

Dr. **P. H. Sykes** (British Oxygen Co., Ltd.) : One of the points mentioned by Dr. Newell was the cost of the oxygen to the steelmaker. The quantity used in the work recorded in this paper is up to 250,000 cu. ft./week. This is, relatively speaking, a very small demand, and therefore it is bound to cost the steelmaker something like the same price as has to be paid when using about the same quantity of oxygen in steel cutting and steel finishing. Any individual foundry consuming oxygen on this scale, whatever the purity, has to face this fact. Nevertheless, the application of oxygen-enriched air to side-blown-converter practice appears to be highly attractive from the economic, as well as the technical, point of view.

If, however, the technique of using oxygen in steelmaking is extended on a substantially greater scale, as in bottom-blown Bessemers, or in much larger side-blown Bessemer plants, such as Dr. Newell has mentioned, a different order of oxygen consumption is achieved, and it is then that substantial reductions in the cost of oxygen can be achieved, bringing it into the realm of the figures which are thought of when the term " tonnage oxygen " is used.

Mr. H. Herne (British Iron and Steel Research Association) : The problem of oxygen enrichment depends largely on cost, in which two factors are involved. Firstly the addition of oxygen to the blast reduces the nitrogen/oxygen ratio, and secondly it alters the progress of the chemical reaction. In the side-blown converter the nitrogen is heated and it promptly goes to waste, in contrast to the open-hearth furnace, for example, where nitrogen acts rather as a reciprocating heat source. We have calculated this loss of sensible heat in the side-blown converter, but other members of the British Iron and Steel Research Association who are here today have studied this in more detail and will, I believe, give their results.

The second factor is the efficiency of oxygen utilization. Table II of the paper gives a mean ratio of (Total Oxygen Used)/(Theoretical Oxygen) for air blowing of about 1·5, and Table III gives a value of about 1·1 with 30% of oxygen in the blast. The two sets of blows needed total volumes of oxygen differing by about 40%. If one has to pay not only blowing costs but also for the oxygen itself, this difference in efficiency appreciably alters the economics of the oxygen enrichment. It is a problem which should be investigated in more detail as a direct way of reducing costs.

The process is, presumably, a complicated physicochemical one. Assuming that the major part of the liquid surface on the converter has the slag pushed aside by the air blast and the metal exposed directly to the air, the mechanism of oxidation would be : (*a*) by a turbulent gas layer, the body of the air blast, (*b*) by a laminar boundary layer between the main gas flow and the relatively stagnant liquid metal, (*c*) by oxidation at the interface between the gas and the metal, (*d*) by the movement of the liquid metal at a speed which is, presumably, considerably less than that of the main gas stream above. I do not know if the metal is in turbulent or laminar flow ; if it is turbulent there would be the additional complication of splitting section (*d*) above into a boundary layer in laminar flow and a turbulent region below it. The movement of the reactants in the liquid metal would be partly by diffusion and, possibly,

partly by turbulent flow in the metal. Concentration gradients must be very large at the surface of the metal.

This kind of process, a balance between rate processes, is not uncommon, and I should like to ask whether it is worth trying to develop some criterion for this balance by which oxygen, and possibly nitrogen, is transferred to the bath, and by which carbon monoxide, or dioxide, is removed. I believe it might be possible to develop some dimensionless group or groups of the variables in the process, such variables as average blast velocity, dimensions of converter, viscosity of the blast, diffusion coefficients, etc., which would give a quantitative value to the balance between the rate processes, and thus specify the efficiency of oxygen utilization. Such a theory would apply to ordinary air blowing as well as to oxygen-enriched blowing.

The first question to answer, however, is whether the economics of oxygen enrichment are likely to justify the attempt to give a theoretical basis to the problem of minimum oxygen consumption.

Mr. **D. J. O. Brandt** (British Iron and Steel Research Association) : I should like to extend a little some of the remarks made by Mr. Herne on the question of the relative effects of oxygen enrichment. Oxygen enrichment of a converter can be regarded as the progressive removal of nitrogen from the sphere of action.

There are three main heat-giving elements in a cupola iron or a basic Bessemer iron—carbon, silicon, and phosphorus. The net thermal output is given by the actual heat of combustion of each of these elements in calories less the quantity of sensible heat which will be removed from the sphere of action by the nitrogen passing through the system when blowing with air. Theoretically, carbon, say 3%, will give about 10 calories per gramme of iron in the bath ; silicon, say 1%, will give something like 50 calories, and 2% of phosphorus will give something like 80 calories, when an air blast is used.

Manganese, and such iron as may be oxidized to iron oxide and lost, give far less heat. At 40% oxygen enrichment there is nearly three-quarters of the total extra heat which should result from 100% enrichment ; at 30% there is between a third and a half. To obtain 40% of oxygen in the blast 35 cu. ft. of oxygen must be added to each 100 cu. ft. of air. To obtain 50% of oxygen in the blast between 50 and 60 cu. ft. of oxygen must be added to each 100 cu. ft. of air. To go right up to 80% it is necessary to add far more oxygen than air.

It is possible to estimate, in a rough and ready manner, to what extent a drop in any one of these elements, such as phosphorus, can be compensated for by an enrichment in the blast. Similarly, a lack of silicon in an acid pig iron may be compensated for by using an enriched blast. Whether such enrichment is practicable naturally assumes that the converter is able to carry the oxygen, and that difficulties with refractories will not be met. Kondakov* has blown 100% oxygen through bottom tuyeres ; but only in one blow at a time, since the tuyeres were no good afterwards. In Germany however, they are blowing, as a regular thing, 30% oxygen through the converters at Maximilianshütte,† and are having no trouble with the bottom tuyeres at all. Irons with only 1·3% of phosphorus are blown.

Dr. **C. H. Desch,** F.R.S. (Past-President, London) : I wish to raise the question of the nitrogen content of the steel. I do not think that any of the analyses given show that. One would expect that, using this process, the nitrogen content of the finished steel would be reduced quite appreciably. For the kind of castings with which the paper mainly deals that would not be important, but in the synopsis it is suggested that there might be an increased used of this process in making ingot steel. When making a low-carbon steel for deep-drawing the question of nitrogen content becomes very important, and it would seem that the use of the oxygen-enriched blast might lead to a reduction in the nitrogen content, which would be advantageous.

* V. V. Kondakov, Bulletin de l'Académie des Sciences de l'U.R.S.S. Classes des Sciences Techniques, 1946, No. 10, pp. 1401–1420. (The Iron and Steel Institute, Translation No. 316).

† F.I.A.T., Final Report No. 1203.

AUTHORS' REPLY

Dr. **W. C. Newell** said in reply : We thank Mr. Cousans for his critical review of the work, and we recognize only too well that the results are applicable only to the particular, and somewhat old, plant from which they were determined, but at the same time it is reasonable to expect such results from the many similar plants which exist, and also that it should be possible to apply the results to different types of steelmaking plant. There were numerous modifications to the way in which oxygen could be used, and it was intended to try some of these in the near future. The present investigation had been designed to demonstrate the effect of oxygen under a simple set of standard conditions. It must be remembered that before this investigation was commenced it was considered to be a very rash enterprise, and the modifications for normal plant procedure were kept to a strict minimum in order to maintain the plant in commercial production.

We appreciate Mr. Catton's remarks very much, but still more do we appreciate his vision, courage, and wholehearted support throughout the investigation, without which it would never have commenced.

The answer to Mr. Hock is that slag analyses were made, and that these show that the slag changed in composition during the blowing operation in conformity with the ideas expressed about varying slag viscosity and its influence in restraining the combustion at the critical stage during the blowing operation. The evidence of the low nitrogen contents, as compared with bottom-blown Bessemers, suggests that slag can act as a restraining influence.

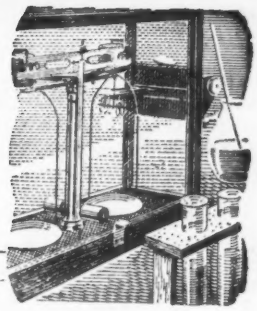
We disagree with Mr. McNair in his suggestion that we have sacrificed flexibility for a higher temperature. Actually the maximum temperature possible has been obtained as a measure of the increase in thermal efficiency, which could be translated into an enhanced degree of freedom in various ways, as indicated. It is not suggested that such high temperatures are normally required.

We thank Dr. Sykes for his note of caution about the future price of oxygen, and we agree with Mr. Herne that more attention should be given in the future to the chemical kinetics of the combustion reaction. Much more could have been said about the theoretical aspects, raised by Mr. Brandt, but these are being considered elsewhere.

In answer to Dr. Desch's point that oxygen enrichment should lead to lower nitrogen contents for the steel produced, the absorption of nitrogen by the metal should depend upon the partial pressure of nitrogen prevailing, and the difference in this partial pressure, when only a moderate degree of oxygen enrichment is employed, is very small. For example, to bring the partial pressure of nitrogen down to half its normal value the oxygen content of the blast would have to be raised to 60%, so that this factor should not be significant unless substantially pure oxygen is employed.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Studies on Anti-Fouling Compositions

By H. Barnes, B.A., B.Sc., Ph.D., F.R.I.C.

FOREWORD

This paper forms part of a series of studies on anti-fouling compositions. The first three papers were published in the December, 1947, issue of the *Journal*. Part I was a general introduction to the whole series. Part II described the probable reactions occurring between the components during preparation of varnish, and Part III gave details of a study of the rate of loss of materials from a series of varnish media immersed in the sea over two consecutive 40-day periods. Part IV, published in the June, 1948, issue of the *Journal*, determined critical leaching rates for a number of common fouling organisms and compared copper loss under service and raft exposure conditions. Part V, published in October, 1948, gave consideration to the behaviour of mercuric oxide in some anti-fouling compositions, paying particular attention to the leaching-rate test. The present paper, Part VI, considers the leaching rate during early stages, and its relation to surface conditions in cuprous oxide compositions.

Part VI—The Leaching Rate during the Early Stages and its Relation to the Surface Conditions in Cuprous Oxide Compositions

SYNOPSIS

The factors governing the initial and later stages of the leaching process of anti-fouling compositions containing cuprous oxide are different, and the initial stages are therefore considered separately.

Dilute solutions of citric acid in sea water are used for studying the available particulate cuprous oxide, since this reagent is almost without action on the varnish media used. The copper extracted by this reagent can be used to estimate the surface-available cuprous oxide. The use of this reagent indicates that the surface-available cuprous oxide is responsible for the initial leaching rate of the compositions. It is pointed out that it is difficult to generalize from the results obtained regarding the effect of various components of the compositions on this surface-available cuprous oxide, since the conditions were not adequately controlled.

Overlying the uniform portion of the paint film, a layer of almost pigment-free varnish may be formed, and the relation of this to the early leaching rates is considered. Some practical considerations with regard to varnish-film formation and its prevention are noted.

Introduction

In Part IV of this series of papers it has been indicated that a fundamental relation between the leaching rate and the anti-fouling performance of an anti-fouling composition exists. It is now proposed to discuss the leaching rate and its variation in relation to the formulation and properties of a number of compositions.

Experience has indicated that the rate at which copper is lost from cuprous-oxide-containing compositions, immediately on immersion, and for a short time subsequently, bears a different relation to the chemical and physical properties from the losses in later stages of the leaching process. It is, therefore, convenient to discuss the initial and early stages of the process separately.

These early stages of leaching are of some practical interest and importance, although they do not contribute to any appreciable extent to the eventual life of a correctly formulated anti-fouling composition.

THE EFFECT OF TOTAL PIGMENT CONTENT: CONTACT LEACHING

If a series of cuprous oxide compositions are prepared with increasing total pigment concentration,

Paper MG/BC/3/49 of the Marine Corrosion Sub-Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 6th December, 1948. The views expressed are the author's and are not necessarily endorsed by the Sub-Committee as a body.

Dr. Barnes, formerly Investigator to the Marine Corrosion Sub-Committee of The Iron and Steel Institute, is now with the Scottish Marine Biological Association.

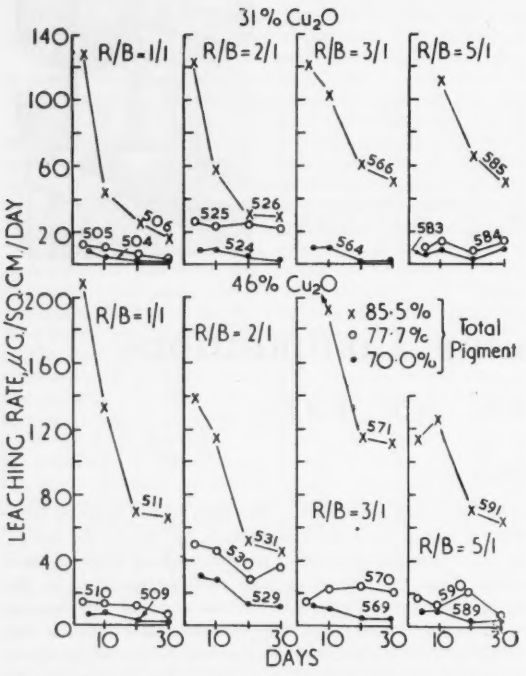


Fig. 1—Initial leaching rate for compositions of varying total pigment content with variable rosin-binder ratios for two series of compositions with 31·1% and 46·6% cuprous oxide content. Composition numbers are recorded on each curve

it is found that, at a given point in the series, there is a very sudden change in the type of leaching curve obtained. This can be illustrated by reference to selected members (31·1% and 46·6% cuprous oxide) of series 495 to 594, which was formulated with both graded poison and total pigment contents : the rosin-binder ratio of the varnish was varied from 1/1 to 5/1. The formulations and early leaching rates are shown in Fig. 1.

At about 77 to 80% total pigment, a distinct change takes place in the initial leaching characteristics of the compositions, and this is independent of the composition of the varnish. It is to be noted that this change takes place at about that proportion of volume required for continuous contact leaching of the pigment particles. If the density of the pigments (cuprous and ferric oxides) is taken as 6·0, and that of the vehicles as 1·2, then the volume proportions in the dry film at 80% pigment content are 44 and 56%, respectively. In the most open packing of spheres, the volume of the latter is approximately 50% of that of the unit cell, and it seems reasonable to assume that at these high concentrations there will be some contact between the particles throughout the film.

The data indicate that, at these high pigment contents, the initial portion of the leaching curve shows little change for large variations in the rosin-binder ratio of the varnish component. There is, however, a tendency for the leaching rate of such compositions, while starting at a similar point, to drop less steeply as the proportion of rosin in the varnish is increased, *i.e.*, as the film becomes more readily attacked. Further, with compositions containing a very high proportion of binder in the vehicle, leaching can take place above a critical pigment concentration. Thus, a composition with 62·4% Cu_2O and 7·8% Fe_2O_3 in 1/1 rosin-binder ratio, has leaching rates of 12, 8, 4, and 3 µg/sq. cm./day, at 3, 10, 20, and 30 days, in contrast to composition 506, as shown in Fig. 1, and this suggests that the release of copper in high-pigment compositions is by some mechanism other than that obtaining in those with a lower pigmentation and a larger proportion of rosin. If, as has been suggested previously, continuous contact between some of the pigment particles is established at these high-pigment compositions, then a mechanism for leaching, namely dissolution of particles allowing access of the attacking solution to other particles throughout the film, is available. Such a mechanism would be independent of the nature of the vehicle, and could take place even in the absence of rosin or other alkali soluble material.

Evidence for such a mechanism is obtained from the action of citric acid solutions on these paints, a reagent also used by the workers in the U.S.A.[1] (1946). As will be shown later (p. 182), a solution of citric acid (0·05%) in sea water has little effect on the rosin-binder varnishes used, and when a normally pigmented composition is leached in successive changes of this reagent, extraction of the copper soon ceases. If one of these high-pigment compositions is

Table I

EXTRACTION OF COPPER FROM LOW AND HIGH PIGMENT COMPOSITIONS BY CITRIC ACID SOLUTION

No. 501 : Cu_2O, 31·1% ; total pigment, 46·6% ; R/B, 1/1
No. 506 : Cu_2O, 31·1% ; total pigment, 85·5% ; R/B, 1/1

	Time, hr. (Successive Periods)							
	1	1	2	2	18	24	24	24
Composition 506								
µg. out/sq. cm.	424	72·0	86·0	66·0	363·0	161·0	271·0	271·0
Rate, µg./sq. cm./hr.	424	72·0	43·0	33·0	20·0	6·7	11·3	11·3
Cu lost, %*	9·9	11·6	13·6	15·2	23·6	29·7	33·7	40·1
Composition 501								
µg. out/sq. cm.	10·6	3·1	2·3	1·9	2·7	1·6	2·6	1·5
Rate, µg./sq. cm./hr.	10·6	3·1	1·2	1·0	0·15	0·07	0·1	0·06
Cu lost, %*	0·25	0·320	0·37	0·42	0·49	0·52	0·58	0·62

* On the basis of a spreading rate of 0·20 g. per slide of 2 sq. in., *i.e.*, 155 g./sq. m., equivalent to 4·28 mg. Cu/sq. cm., in both these compositions

similarly extracted with this reagent, cuprous oxide is dissolved continuously until the slide is virtually exhausted. This can be illustrated by reference to the contrast in behaviour of compositions 501 and 506. Table I shows the copper extracted by successive changes of the citric acid reagent, and the percentage of the total copper removed from these two compositions.

That this hypothesis is correct, is also substantiated by the fact that the films with high-pigment content can be completely leached of copper by these citric acid solutions, even when the varnish contains no rosin ; a film based on a combination of Aroclors (solid and liquid) can be freed from cuprous oxide in 48 hours. Further, if the pigment content is high, and entirely of cuprous oxide, then at the end of such citric acid treatment a semi-transparent varnish is left on the slide.*

On the preceding hypothesis, it would be expected that, as the percentage of the pigment is increased, the surface of the film should then become covered with particles, at some point, and further increase in poison content would not give any increase in the initial leaching rate (sea water). The results in Table II indicate that such a maximum is reached ; the initial rate was measured using the standard apparatus, but leaching was only allowed to proceed for five minutes in order to prevent retardation due to accumulation of products in the leaching bath (*see* Part IV[2]).

Only the order of this agreement is stressed, since the packing may be less open, as in a hexagonal close packing of the particles, and the area of contact between the particles and the matrix may not be negligible. Further, at these high rates of loss, the rate of stirring is tending to become a limiting factor in the rate of solution of the cuprous oxide.

Table II

LEACHING RATE AT HIGH PIGMENT CONTENTS

Cu_2O as only pigment present

Cu_2O, %	Initial leaching rate, μg/sq. cm./day
84	248
88	230
92	272

Little work has been carried out on these high pigment compositions as practical anti-fouling paints. Attention will therefore be confined to compositions with insufficient pigmentation to give contact leaching. For further details of such compositions, *see* Ferry and Ketchum (1946).[1]

THE INITIAL LEACHING RATE AT MODERATE PIGMENT CONTENTS

Below pigment contents necessary for contact leaching the extraction of copper by acid citrate solution soon becomes extremely small. Further data are given for a number of such compositions in Table III.

It is suggested that, since the acid solution is not able to break down the matrix by solution of the rosin, this citric soluble copper represents cuprous oxide particles on the surface of the film, and is capable, therefore, of direct attack by any solution in which it is soluble. It may be argued that most of the pigment will be wetted by the medium, but a thin layer of the latter seems unable to prevent attack by the solutions used. In all compositions investigated (in which the binder is Bedesol stand-oil) the major extraction of this surface material is rapidly accomplished, but there is always a residual and comparatively small extraction which continues for long periods. The latter may be due to a slight attack on the matrix or to diffusion processes, and for comparative purposes, little error will be introduced by using the amount extracted in 24 hr. as a measure of the surface cuprous oxide.

On this hypothesis, the rate of solution in the early stages of extraction in citrate should, at any time, be a function of the area, and hence, of the weight of cuprous oxide remaining on the surface. The latter can be calculated from the total amount extracted and the amount lost in a given time. Figures 2 and 3 give data for two compositions, the rate being measured over intervals of time as short as convenient for the analytical technique employed. These results substantiate the theory outlined above. The fact that the curve is not linear in the very early stages, suggests that, initially, the solution of the particles takes place in such a manner that the area decreases rather more rapidly than does the mass, a phenomenon also observed by other workers[1] in their work on surface cuprous oxide.

Further, the initial leaching rate in sea-water solution should be proportional to the total citrate-extractable copper, if the latter is a measure of the area

* A point of interest in this connection is that, at the end of such an extraction, there is always a small amount of red residual matter scattered throughout the otherwise clear cuprous-oxide-free film : it is metallic copper with which the commercial cuprous oxide is known to be contaminated and which, unlike cuprous oxide, is insoluble in the dilute citric acid solution.

Table III

EXTRACTION OF COPPER BY CITRIC ACID SOLUTION FROM MODERATELY PIGMENTED COMPOSITIONS

No.	Cu_2O, %	Total pigment, %	Rosin-Binder ratio		Time, hr. (Successive Periods) 1	1	2	6	14	24	24	24
504	31·1	70·0	1/1	μg. out/sq. cm.	11·3	1·9	0·2	0·7	0·9	1·5	—	—
				Rate, μg./sq. cm./hr.	11·3	1·9	0·1	0·11	0·06	0·06	—	—
										48 hr.		
575	15·5	46·6	5/1	μg. out/sq. cm.	8·8	0·5	0·0	0·6	0·6	0·9	0·6	
				Rate, μg./sq. cm./hr.	8·8	0·5	0·0	0·1	0·04	0·2	0·03	
577	15·5	62·1	5/1	μg. out/sq. cm.	10·8	0·5	0·0	0·8	1·6	3·4	2·4	
				Rate, μg./sq. cm./hr.	10·8	0·5	0·0	0·13	0·11	0·07	0·1	
572	62·2	70·0	1/1	μg. out/sq. cm.	24·6	1·5	0·9	1·6	2·9	6·1	4·7	
				Rate, μg./sq. cm./hr.	24·6	1·5	0·45	0·26	0·21	0·13	0·2	

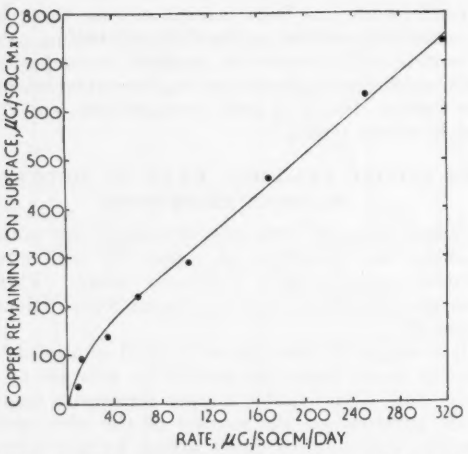


Fig. 2—The leaching rate (citric acid) and residual cuprous oxide for composition 495

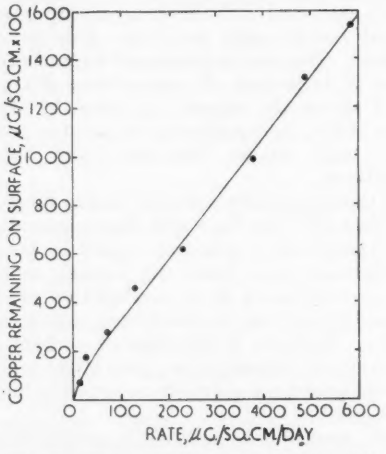


Fig. 3—The leaching rate (citric acid) and residual cuprous oxide for composition 501

exposed and available for the normal leaching process.*

This has been verified on a number of compositions, a typical series of results being shown in Table IV.

It would seem then that the citrate-extractable copper is a measure of the surface exposed particles

Table IV

INITIAL LEACHING RATE AND SURFACE COPPER

All compositions : rosin-binder ratio of 3/1

Composition No.	Total extractable copper, μg/sq. cm.	Leaching Rate, μg/sq. cm./day
205	23	12·7
206	38	15·9
207	54	21·3
208	41	14·3
209	57	17·9
210	90	27·2

of cuprous oxide, and that this surface cuprous oxide determines the initial leaching rate of any composition. Two convenient modes of expression may be used for this surface cuprous oxide ; it may be expressed in terms of the fraction of cuprous-oxide required to cover the surface, or it may be related to concentration of cuprous oxide in the composition. The total possible weight of particles (open packing, *see* p. 181) in such a completely covered surface can be calculated on the assumption of a density of 6 for the cuprous oxide and 1μ for the particle diameter, and is given by $10^8 \times 3 \times 10^{-6} = 300$μg./sq. cm.†

If the particles were partially embedded in the surface of the matrix then, since the initial leaching rate is proportional to the area exposed, it would be reduced for a given weight of particles, but for complete covering, the weight extracted by the acid solution would not change.

The majority of compositions dealt with have been composed of two pigments, cuprous oxide and the inert filler, iron oxide. In order to calculate the fraction of possible surface cover, it is necessary to assume that the two pigments on the surface are in proportion to their contents in the paint, that is, to assume that there is no preferential concentration of one pigment in the surface layers. Thus, in a composition of which 50% of the total pigment was cuprous oxide, an amount of cuprous oxide corresponding to 150μg./sq. cm. would represent a "saturated" surface. The percentage of this possible saturation value may be termed the percentage cover.

In the alternative method of expression, the concentration in the surface is calculated from the acid extraction value and the assumption that it is contained in a layer 1μ thick (the diameter of the cuprous oxide particle). These values for several compositions are given in Table V. The percentage of the bulk concentration in the surface may be termed the percentage saturation.

It is clear that the surface in these compositions is far from completely covered by particles and that, when compared with the body of the film, there is a reduction of concentration at the surface.

An investigation of the surface cuprous oxide and

* This is obviously true if all the exposed particles project to the same extent. It has been shown to be true if the exposed particles protrude in random distribution between 0 and $2r$, where r is the radius of the particles.[1]

† It is appreciated that the actual size of the ultimate particles of the pigments used will vary according to the mode of preparation of the pigments, and may vary from one commercial batch to another. Further, it is also realized that, when these pigments are compounded in a paint medium, dispersion to the ultimate particles rarely takes place. However, on many of the compositions used the dispersion was very satisfactory, and as a first approximation it will be considered that the ultimate particles are spheres of 1μ dia., although aggregates and particles up to a dia. of 6μ are found. Indeed, it is difficult to ascertain by the usual methods the state of the particulate matter, as present in the actual paint. The use of this value gives a maximum value for the actual surface concentration when derived from the citric soluble copper per sq. cm. of plain surface, and also a minimum value for the possible weight of surface particles. When the surface cuprous oxide is expressed as a percentage of either the possible cover, or of the bulk concentration, the values are therefore maximal if 1μ is taken as the particle diameter for cuprous oxide.

Table V

CUPROUS OXIDE IN SURFACE OF COMPOSITIONS

No.	Cu_2O %	Total Pigment, %	Rosin-Binder Ratio	Cu_2O, μg./sq. cm.	Cu Complete Cover, μg.	Cover, %	Concentration, g./l Bulk	Concentration, g./l Surface	Saturation, %
496	15·5	54·4	1/1	7·2	86	8·4	320	72	23
501	31·1	46·6	1/1	15·2	200	7·6	620	152	25
502	31·1	54·4	1/1	9·5	171	5·6	650	95	15
503	31·1	62·1	1/1	26·2	150	17·4	720	262	36
521	31·1	46·6	2/1	8·3	200	4·2	620	83	14
541	31·1	46·6	2·5/1	14·0	200	7·0	620	146	23
561	31·1	46·6	3/1	14·6	200	7·3	620	146	24
577	15·5	62·1	5/1	15·3	75	20·4	350	153	44
581	31·1	46·6	5/1	15·5	200	7·8	620	155	25

initial leaching rates of a series of compositions with graded components, using citric acid, should give information on the relation of surface cuprous oxide to the components of the composition, both as regards the amount and the mean position in the surface. With a small series, prepared at the same time, results were obtained from which tentative conclusions could be drawn, but it soon became apparent that results which could be reproduced were very difficult to obtain. It was hoped that by using a doctor-blade technique some of the sources of error would be eliminated, but little greater consistency and reproducibility of results was obtained. It is suggested that, in order to extend this work, much more careful control of conditions, particularly during the drying of the composition, would be required, and the results can only be interpreted as applying to the conditions under which the slides were painted out—conditions whose factors were not determined and which varied from time to time. Table VI shows the initial leaching rate and extractable copper for a series of compositions with constant cuprous oxide content and variable rosin-binder ratio.

Since, in general, the leaching rate per unit of copper exposed decreases with increasing rosin-binder ratio, it suggests that, under these conditions, the surface-exposed particles tend to be more deeply sunk (thus exposing less copper per unit weight) in those compositions containing a greater proportion of rosin.

This problem of surface copper is one of considerable complexity, since it is dependent upon many variables. In the paint itself the degree of wetting and reaction of the pigment and vehicle are important factors ; in the finished paint, the viscosity and flow properties must play a part. The interactions of these factors with the forces involved, when the paint dries with the removal of solvent, will determine the point at which gelling takes place with the consequent " fixing " of the particles in the surface.

Until the factors controlling these phenomena are more fully understood, and the forces can be brought under more careful control, little advance will be made in elucidating the surface conditions of anti-fouling films, but it seems that when this is done, a technique like the one described will be found of considerable value. However, although the surface cuprous oxide determines the initial rate at which copper is lost from a composition, such surface copper cannot maintain a leaching rate adequate to prevent fouling for an appreciable period.

Table VI

INITIAL LEACHING RATE AND SURFACE COPPER

All compositions have 31·1% Cu_2O and 46·6% total pigment.

Composition No.	Rosin-Binder Ratio	Citric extracted Copper, μg./sq. cm.	Initial Leaching Rate, μg./sq. cm./day
501	1/1	13·5	11·4
521	2/1	7·4	7·0
541	2·5/1	12·5	8·0
561	3/1	12·9	9·1
581	5/1	21·6	7·6

THE FORMATION OF VARNISH FILMS

The initial leaching rate depends then on the surface-available cuprous oxide remaining on the surface of the composition. The behaviour of the uniform portion of the film with regard to leaching will be considered in a later paper. Paint films, however, are rarely completely uniform, even when the surface-exposed material is neglected, and frequently an upper layer of pigment-poor varnish is found, in which any surface-available cuprous oxide is embedded. Such a layer of varnish can modify the behaviour of a film very considerably, and its formation can even render ineffective the anti-fouling properties of an otherwise satisfactory composition. The formation of varnish films is usually due to incorrect adjustment of the formulations in regard to their physical, as distinct from anti-fouling, properties, although the formation of such a film is dependent to a considerable extent on the conditions under which the film dries.

In compositions in which varnish films are of marked thickness, the initial leaching rate is low, since the factors tending to produce varnish films also tend to reduce the particulate matter remaining on the surface, *i.e.*, the combination shown in Fig. 4*b* is rarely found.

The effect of varnish-film formation and surface cuprous oxide can be illustrated by reference to the

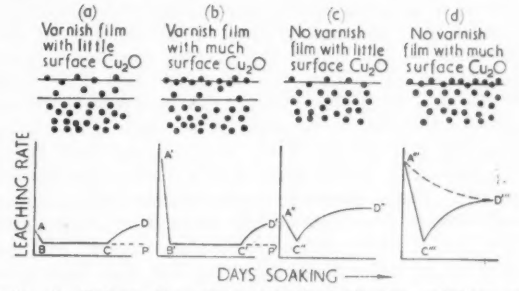


Fig. 4—Schematic representation of the relation of surface cuprous oxide, varnish-film formation and the resultant leaching rate.

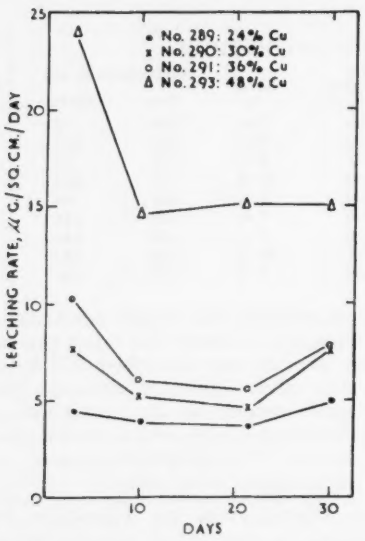


Fig. 5—Initial leaching rates of a series of compositions with graded cuprous oxide contents showing independence of length of initial portion in respect of cuprous oxide content.

four theoretical possibilities shown in Fig. 4, in which the surface condition and the corresponding leaching-rate graphs are illustrated. The length of the portion AB depends upon the amount of surface-exposed cuprous oxide, and theoretically, if no further cuprous oxide is being released by dissolution of the matrix, then the duration of this portion of the leaching curve should be approximately the same in all compositions. Increase in surface-exposed cuprous oxide gives a corresponding increase in the initial and subsequent rates until such surface particles are exhausted, but does not increase the time taken for its exhaustion, since the rate is proportional to the exposed cuprous oxide present at any time. This is illustrated for a number of compositions by Fig. 5, in which the compositions referred to had a variable cuprous oxide content, in a constant varnish, which was comparatively resistant to attack. The portion BC in Fig. 4, represents the dissolution of the pigment-poor (or even in some cases almost pigment free) varnish, and, if not too extensive, is roughly proportional to the thickness of the varnish film. The release of copper, subsequent to the removal of this varnish film, will depend upon the formulation of the composition, but unless the varnish contains a large proportion of binder, the leaching rate will tend to rise as particulate cuprous oxide is exposed. When no varnish film is present, it is often difficult to separate the effects of the surface and underlying cuprous oxide, particularly with a moderately soluble matrix. Under these circumstances the surface copper will tend to give a curve AB, BC will be absent, and the initial curve with a soluble matrix will be followed by a rise in leaching rate (Fig. 4*c*). However, in general, removal of the matrix and dissolution of surface copper are simultaneous, so that the leaching curve is a resultant of two distinct processes and often takes the form shown by the dotted line in Fig. 4*d*.

The effect of varnish-film formation can be estimated from the length of the portion of the curve BC. If this were of a considerable length, days or weeks, and if the composition were exposed to fouling conditions immediately on immersion, then the composition would foul before the varnish film had been dissolved. The approximate time taken to dissolve such varnish films can be calculated, and the values for a series of Bedesol-rosin varnish 10μ thick, given in Table VII, are obtained using the rates of solution already given.[3] The density of rosin is assumed to be 1·2, and it is also assumed that only rosin is being lost and that this rosin is lost uniformly.

It has also been shown that, in the later stages of the solution of varnishes, changes take place in the process, with the slowing down of the rate of loss, and it has been suggested that precipitation of material in the film causes such retardation by preventing access to the underlying varnish. With thick varnish films, this may inhibit release of material from the underlying uniformly pigmented layers so that they may never function as would be expected from their formulation. Further, it will be shown that for long life compositions a high cuprous oxide content, in conjunction with a moderately resistant varnish, is desirable. The use of only moderately soluble varnishes to achieve this purpose increases the danger due to varnish-film formation, since the more resistant varnishes take longer to dissolve, and to expose the underlying uniform and adequately formulated matrix. Some values for three compositions showing varnish-film formation are given in Table VIII. The leaching rate is only beginning to rise at the 29 to 60 day period, and this, in conjunction with the values given in Table VII, suggests a varnish film whose thickness is of the order of 10μ for these compositions.

The formation of varnish films has not yet been intensively studied, but it has been noted that the drying conditions are of importance both in relation to surface particles and to varnish film formation. With a given composition, rapid drying tends to increase surface cuprous oxide and to decrease varnish film formation owing to increased evaporation forces

Table VII

TIME REQUIRED TO REMOVE VARNISH FILMS : BEDESOL/ROSIN COMPOSITIONS

Rosin, %	Rate of Loss; μg/sq. cm./day	Time required to remove layer 10μ thick, days
87·5	114	9
83·3	91	11
75·0	41	22
71·4	24	36
66·6	6	133

Table VIII

LEACHING RATE AND VARNISH FILM FORMATION

Rosin-binder ratio, 3/1 : Total pigment content, 54·5%

Comp. No.	Cu_2O, %	Leaching Rate at days soaking, μg./sq. cm./day				
		5	11	19	29	57
556	15·5	5·6	6·3	2·4	1·9	2·9
562	31·0	6·3	9·1	2·0	2·2	12·4
567	46·5	10·2	12·0	3·5	2·8	21·7

Table IX

COPPER LEACHING RATE AND DRYING CONDITIONS

Drying	Leaching Rate at days soaking, μg./sq. cm./day						
	3	10	19	28	68	84	122
2½ hr. normal air conditions	11·9	5 3	7·4	5·5	5·4	6·2	6·0
2½ hr. fan drying	17·9	9·4	15·7	11·3	7·1	8·9	6·3
2½ hr. outside	37·4	15·1	24·5	18·2	7·9	12·2	8·8

under such conditions. The initial leaching rates of a composition dried under various conditions are shown in Table IX.

For this reason, when painting out control panels for service tests, as distinct from comparing a series of experimental formulations, it is desirable that the control panels should be painted, as far as possible, under the same conditions as regards drying. Otherwise the initial, and possibly subsequent, behaviour of the two sets of the compositions need not be identical.

The simplest method of preventing such varnish films is to add materials which impart structure to the compositions, as for example, in thixotropic compositions. Thus, compositions based on copper soap media always have a high initial leaching rate, and even small amounts of soaps added to other compositions will often prevent varnish-film formation under any drying conditions. Compositions based on high polymers, or containing moderately large quantities of substances such as Alloprene or Lustron, likewise have very high initial leaching rates, and varnish-film formation is completely suppressed.

SUMMARY

It is shown that, with anti-fouling compositions containing cuprous oxide, the type of initial leaching curve changes at a definite pigment concentration. This change is almost independent of the nature of the matrix of the paint, and it is suggested that it is related to the production of partial continuous contact of the pigment particles. This is substantiated by a study of the action of citric acid solutions on compositions with graded pigment contents.

Sea-water solutions of citric acid (0·05%) are almost without action on the matrix components used, and extraction of a film, with this reagent, is thought to cease when all the available surface cuprous oxide has been removed. It is shown that the initial leaching rate of a composition is determined by this available cuprous oxide on the film surface. The effect of various factors on this surface material is stressed, and it is pointed out that until conditions are more adequately controlled, it is difficult to generalize concerning the effect of components on available surface cuprous oxide.

Two methods of expressing the surface cuprous oxide are given, and it is shown that, in many of the compositions studied, the surface is not " saturated " in respect of particulate matter.

The formation of films of pigment-poor varnish overlying the uniform portion of the film is considered, and the type of leaching curve obtained under a number of generalized conditions is discussed.

References

1. J. D. FERRY and B. H. KETCHUM : *Industrial and Engineering Chemistry*, 1946, vol. 38, Aug., pp. 806–810.
2. H. BARNES : *Journal of The Iron and Steel Institute*, 1948, vol. 159, June, pp. 175–185.
3. H. BARNES : *Ibid.*, 1947, vol. 157, December, pp. 587–600.

A Note on the Metering of Crude Producer Gas in a Horizontal Main

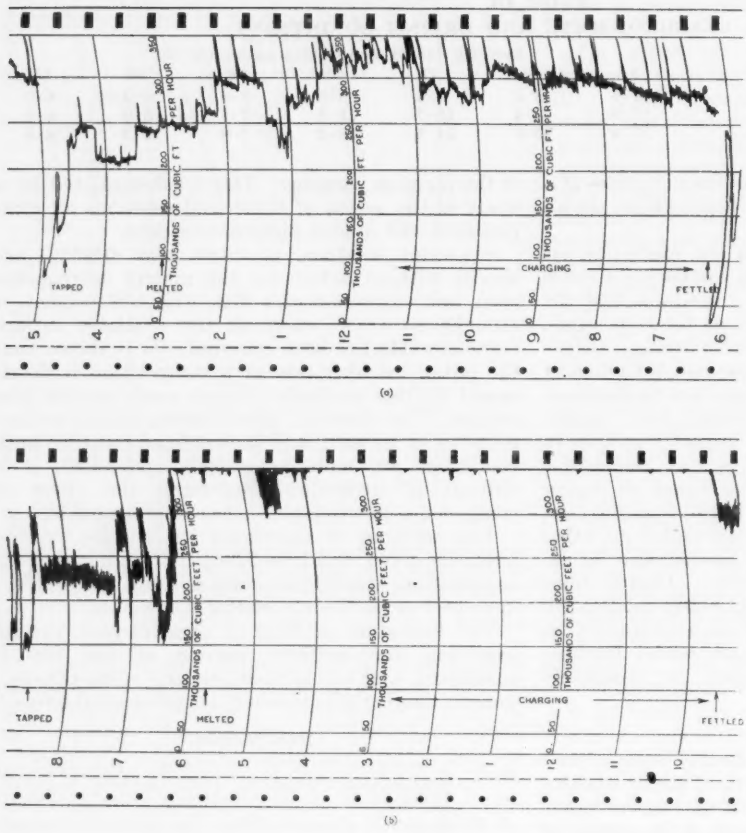
By W. G. Cameron

The problems associated with flow measurement of hot, tarry producer gas are discussed, and a technique is described which is applicable to plants where vertical stretches of main suitable for location of the metering throat are not available. In the course of this work the occurrence of unexpected variations of recorded flow led to the installation of a recording gas calorimeter, which, it is suggested, is a valuable aid to routine control of gas production.

IT is generally recognized that it is desirable to meter and record the supply of fuel gas to steel melting furnaces, but the difficulty of metering the crude tarry producer gas which is often used has prevented the widespread application of gas metering in such cases. In recent years, however, a number of works have succeeded in metering crude producer gas to the degree of accuracy required for routine control. The most common method has been the use of a firebrick orifice,[1] but other methods utilize a steel-plate orifice, withdrawn during burning-out periods,[2] and the measurement of the pressure drop across a valve.[3, 4] The chief difficulty of measurement, apart from the tar and dust content of the hot gas, is that most installations cannot afford the small permanent pressure loss caused by an orifice, and about two years ago a new method was developed

Paper No. SM/AA/128/48 of the Open-Hearth Instruments Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 7th December, 1948. The views expressed are the author's, and are not necessarily endorsed by the Sub-Committee as a whole.

Mr. Cameron is Assistant Melting-Shop Manager at the Lanarkshire Steel Co.



by Dall and Pluck,[5] in which a refractory concrete Venturi, causing little permanent pressure drop, was used to produce the pressure difference. Dall and Pluck also introduced the system of cleaning the throat with compressed air jets, which are said to give much more satisfactory removal of tar and other deposits than the steam jets hitherto employed.

Although these measurement methods could theoretically be applied to any suitable location, they are, in general, only really successful when used in vertical stretches of main, probably because, in vertical location, deposits can be blown, or will drop down, into a space where they will not interfere with measurement. Nevertheless, it is not possible to find a suitable vertical position in many gas-main layouts. One or two works, in which there has been available a straight horizontal length of main, but no suitable vertical stretch, have tried putting a construction in

Fig. 1—Typical flow charts during preliminary tests:
(*a*) Third charge of week;
(*b*) Last charge of week

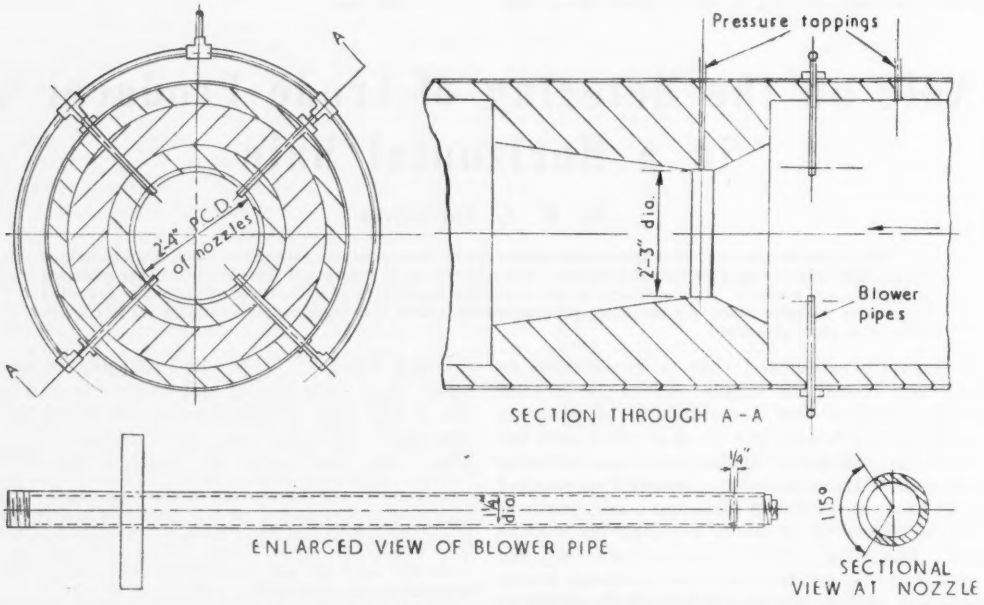


Fig. 2—Gas metering Venturi, showing design of blower pipes

the horizontal section, using a technique similar to that used in vertical positions. Until recently the results have not been very satisfactory, but the present note describes a modification of the Venturi technique, which has now led to satisfactory metering in a horizontal main.

At the works of the Lanarkshire Steel Co. it was decided, some time ago, to meter the gas to one of the 90-ton fixed furnaces. The only suitable length for the insertion of a pressure-differential device was a horizontal length of 54-in. dia. main, where the crude gas temperature was 550° C. At first the type of construction recommended by Dall and Pluck was followed, with similar blowing pipes turned into the horizontal position. Figure 1 shows the type of chart obtained with this arrangement, and it will be noted that, although a satisfactory record was obtained during the first few charges of the week, the readings tended to rise until the pen was off the scale during the entire period of high gas demand. This clearly indicated choking of the Venturi, although the blowing schedule was faithfully observed. Visual inspection at the weekends did not reveal any obvious obstruction, but, since the opening of the inspection door had to await complete removal of the gas main, an appreciable period of burning time had elapsed before close inspection was possible. This period, of one or two minutes, was probably sufficient to dislodge the soot accumulations formed in the metering throat. The inspection did reveal, however, that the blowing pipes had sagged, and were no longer directed on to the required surface of the Venturi.

It was clear that the installation successfully used in a vertical position could not merely be turned on its side for use in a horizontal main. A new type of blowing-pipe layout was therefore designed (*see* Fig. 2). The Venturi is of the usual design recommended by the suppliers of the flow meter, but the blowing pipes are of the pattern shown, four being inserted radially. The correct depth of immersion was determined by experiment, the pipes being withdrawn or pushed in until there was no sign of making up during the week. Figure 2 shows the depth of immersion in this particular plant, but in a layout of different dimensions it may be necessary to redetermine the depth by trial. Only a few weeks' operation is needed for this, as the correct position is easily found.

Figure 3 shows sections of chart obtained with the modified installation, one time taken early in the week and one late. In contrast with Fig. 1*b*, it will be seen that there is no evidence of 'make-up'

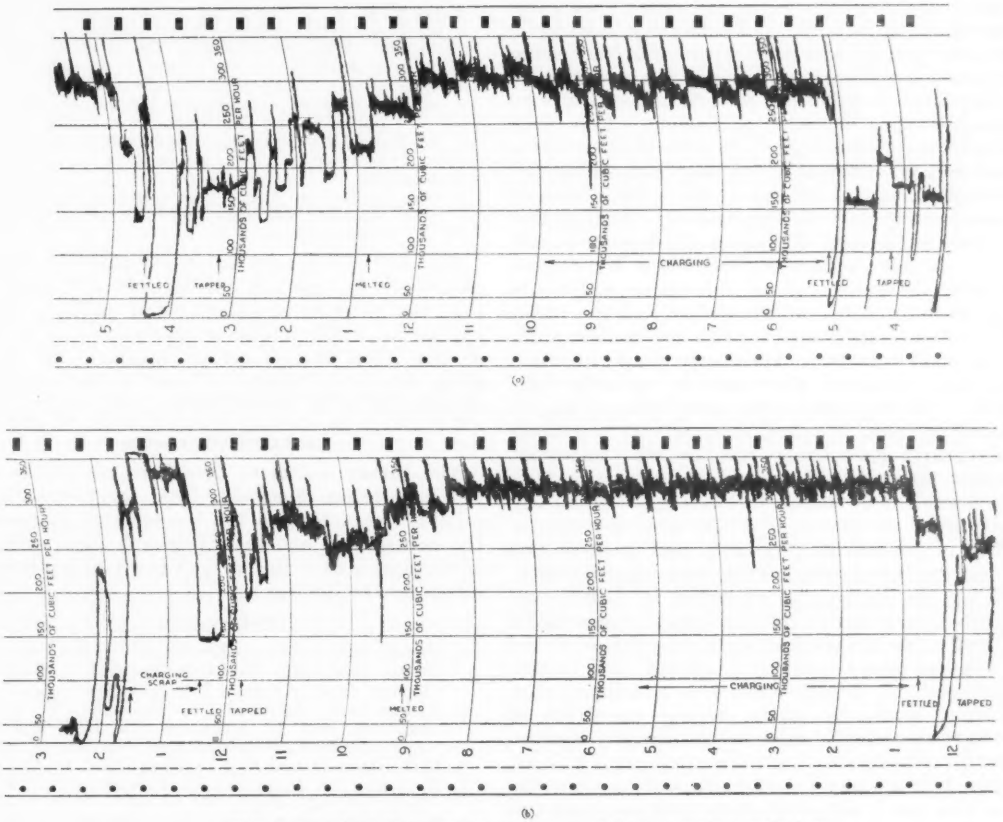


Fig. 3—Typical flow charts using modified scouring technique: (*a*) Third charge of week; (*b*) Last charge of week

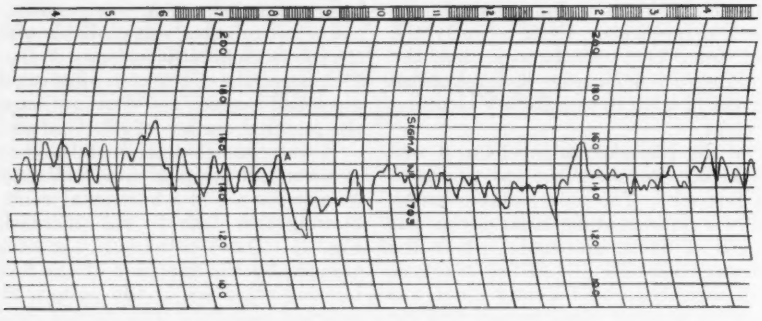


Fig. 4—Typical record of gas calorific value

during the week. This installation has now given satisfactory service for nine weeks. Air blowing is carried out by hand every 4 hr., and the pressure pipes require rodding through twice a week ; it has not yet been considered worth while to install automatic devices for attending to these items.

A trouble occasionally experienced with crude-producer-gas metering, particularly where applied to the output from the hand-charged static gas producers, is for the metered flow of gas to increase at the same time as the gas apparently diminishes in the furnace. At the writer's works, this effect, during the earlier stages of metering, was sufficiently marked to make the furnace operators report that the meter was connected the wrong way round. The phenomenon can be traced to inefficient producer operation, *e.g.*, delayed charging or severe channeling, which gives a rush of hot, dense (high CO_2) gas. This creates a higher pressure differential (*i.e.*, meter recording) for a given flow, and, at the same time, a diminution of furnace heating power, owing to lower calorific value and lower luminosity. The effect of temperature and density change is normally corrected by factors applied to the meter readings, but where gas is made in machines from reasonable quality coal the variations in temperature and density are usually sufficiently small to make it unnecessary to apply routine corrections, provided the meter is correctly calibrated. At the time of the start of metering at Lanarkshire, coal supplies were of very uncertain quality, and gas-making practice was somewhat irregular, so that variations in gas quality gave a certain amount of trouble in metering. These early difficulties drew attention to the need for stricter control of gas-making procedure, and to assist this a continuously recording gas calorimeter was installed. This was similar to that described by Lomas and Mayorcas,[6] but whereas their calorimeter was installed for the purpose of a special test, the apparatus referred to here has been running continuously as a routine control for 12 months, and it is considered that attention should be drawn to the possibility of recording the calorific value of hot raw producer gas (after tar removal) as a routine control on gas making. Figure 4 is a sample record selected to show the maximum gas-quality variations obtained, and also to indicate an abnormality in producer operation (point *A*) which gives rise to the condition, noted above, of increased indicated flow accompanied by apparent diminution of gas in the furnace.

The calorimeter records, on installation, were found to agree with gross calorific values as calculated from samples analysed in the Orsat apparatus, and in the interval frequent tests have not given any reason to doubt the calorimeter's value for control purposes. Regular attention is, of course, necessary to maintain the equipment in good order and to ensure freedom from trouble, the routine operations being established as follows :

Every 48 hr.
- (*a*) The vertical offtake pipe is rodded
- (*b*) The tar traps on the 2-in. dia. delivery pipe are drained

Weekly
- (*a*) The internal expansion tube and the chimney outlet of the calorimeter are brushed
- (*b*) One of the duplicate gas washers is removed and cleaned

Fortnightly
- One of the duplicate gas purifiers is removed, cleaned, and repacked with glass wool and Irish bog ore.

To sum up, it may be stated that the normal controls on gas use and quality applied to clean gas (*e.g.*, the metering of quantity and quality), can be applied to crude producer gas supplying a steel melting shop, though certain modifications to the usual measuring technique have to be applied if metering must be carried out in a horizontal main.

Acknowledgments

The author desires to thank the management of the Lanarkshire Steel Co., Ltd., for permission to publish this note, and the Steelmaking Division of the British Iron and Steel Research Association for advice during experiments with new blowing arrangements for the Venturi.

References

1. Unpublished method developed by the Iron and Steel Industrial Research Council. (Now the British Iron and Steel Research Association.)
2. J. Sinclair Kerr, J. V. Morgan, W. Goldsbrough, and D. Binnie : *The Iron and Steel Institute*, 1938, *Special Report No.* 22, pp. 65–81.
3. R. J. Sarjant and E. J. Barnes, *Ibid.*, pp. 238–275.
4. R. C. Baker : *Journal of The Iron and Steel Institute*, 1947, vol. 157, Sept., pp. 81–88.
5. H. E. Dall and J. Pluck : *The Iron and Steel Institute*, 1946, *Special Report No.* 37, pp. 35–38.
6. G. Lomas and R. Mayorcas, *Ibid.*, pp. 44–48.

Plastic Strain and Hysteresis in Drawn Steel Wire

By R. S. Brown, M.B.E., F.I.M.

SYNOPSIS

Forms of test applicable to wire are briefly reviewed and it is suggested that none of the tests normally applied can be used to assess the properties of wire required to withstand dynamic stresses. Considerable importance is attached to stress/strain characteristics at loads up to 75% of the ultimate tensile strength, and curves involving high magnification of strain are shown, in which important changes in plastic properties exhibited by drawn wire when subjected to static and cyclic loads and after passing round pulleys, are discussed in relation to the behaviour of colliery winding ropes. The effect of temperature during wire-drawing is examined and some comments are made relating to the behaviour of heat-treated wires when subjected to combined bending and dynamic stresses.

DESPITE much published work relating to the mechanical properties of drawn steel wire, considerable confusion and misconception still exists among engineers and users of wire regarding the elastic and plastic properties of this cold-worked material. Information on this subject is widely scattered, and for this reason the significance of these fundamental properties has not been sufficiently appreciated in relation to the behaviour of wire under conditions of nearly static loading, as in stay wires, for example, or under conditions of cyclic tensile stresses combined with bending, as in wire ropes.

It is customary to determine the suitability of wire for wire ropes and other purposes by means of torsion and bend tests. No attempt has yet been made to correlate the results of these tests with the behaviour of the wire in service, but it is clear that none of the tests normally applied can be used to predict its life under any given condition.

Steel wire is probably the only form of metal used in engineering practice which is required to be bent repeatedly under conditions of high initial stress, and it is suggested that it is due to the peculiar properties associated with cold-worked steel that it is able to withstand these arduous conditions.

In this paper an attempt has been made to assemble current data, together with the results of investigations made by the author over the past few years, and at the same time to illustrate how stress/strain properties affect the performance of wire used for ropes and other purposes.

TESTS NORMALLY APPLIED TO WIRE

In the first place it is desirable to review current methods of testing wire and to show how they fail to provide useful information relating to fundamental properties which influence performance in service. It is perhaps true that the existing testing procedure will detect wire suffering from gross defect but it will give no information on the usefulness of wire for a given purpose.

Tensile Test

The tensile test can be nothing more than a standard of reference. As applied to severely drawn wires, values of breaking load convey little useful information in the absence of more precise knowledge of strain characteristics. For example, a wire manufacturer may be asked to supply both spring wire and rope wire, which are manufactured under quite different conditions so as to induce properties required for these widely diverse purposes. The maximum tensile stresses may be identical and thus cannot convey any information of the true properties of the two wires.

Torsion Test

In the torsion test one end of the wire is gripped and the other end is rotated until fracture occurs, one of the grips being capable of axial movement to allow for change of length of the specimen during the test. The number of twists is usually proportional to the length of the wire and the test is standardized on a gauge length of 100 diameters. This test is of historic interest and has become firmly established in the wire industry in this country, where it enjoys a popularity not accorded to it on the Continent. It is difficult to see what precise property of drawn wire it defines, although it has considerable value when used qualitatively for the detection of surface flaws. In the past, high numerical values obtained in this test reflected in some measure that extreme degree of fibrousness induced by grain enlargement during the air-patenting heat-treatment followed by the very severe cold work performed in order to achieve the high tensile strengths required for many purposes. Much wire produced in this way was demonstrably brittle despite very high numerical values of twists, and for this reason the torsion test must be viewed with a more critical eye if progress is to be made in the production of wire having a high resistance to fatigue failure.

Reverse Bend Test

The reverse bend test has not been properly standardized in this country, although on the Continent, where much importance is attached to it, bend testing machines possessing excellent characteristics are available. The test is useful in assessing freedom from brittleness in drawn steel wire, and

Paper MW/D/66/47 of the Drawing Committee of the Mechanical Working Division of the British Iron and Steel Research Association, received 10th September, 1948. The views expressed are the author's, and are not necessarily endorsed by the Committee as a body.

Mr. Brown is at Messrs. Rylands Brothers, Ltd., of Warrington.

when properly applied it is a better criterion for rope wire than are other tests at present in use ; it must, however, be related to the conditions under which the wire is to be used, or undue importance may be attached to high numerical values.

Fatigue Test

Endurance properties of wire determined on conventional machines have been shown to be affected to a greater degree by the condition of the wire surface than by modifications in method of wire production,[1] and in one case[2] at least, an attempt to assess the properties of wire for a particular purpose by this test has been most misleading. Fatigue breakdown in wire ropes in service rarely occurs at the original wire surface, and wire failures are more usually associated with wear, when fracture of cold-worked films initiates failure, or with corrosion, which is known to accelerate the development of fatigue cracks. For this reason the use of fatigue testing machines has proved disappointing, and approach to the problem of increasing the endurance of wires must be made by other methods.

Elongation at Fracture

Whatever value may be ascribed to the elongation at fracture as a test for rigid engineering members, it has little or no significance when applied to wire. Exceptions may be made in the case of mild-steel wires required to undergo severe plastic deformation, as in the manufacture of cold-forged bolts, or in the case of mild-steel wires that are to be severely bent round small radii for forming operations.

The high elongation at fracture possessed by a hot-rolled or heat-treated rod before wire-drawing is rapidly destroyed with increasing degrees of cold work, so that hard-drawn wires such as rope wires and spring wires possess little residual elongation, and most of this is due to necking-down at the moment of fracture. The total amount of elongation at fracture can be trebled by simple heat-treatment at low temperature, for example in hot-galvanizing, but the quality of wire for all purposes is not necessarily improved thereby.

Reduction of Area

The foregoing tests are those generally applied to wire, but in some specifications a minimum reduction of area at fracture is required. This quantity is difficult to measure accurately on wires of small diameter and it is doubtful whether it reflects any useful property.

Stress/Strain Tests

For some years stress/strain tests have been applied in the author's laboratory to define properties of wires for various applications, and particularly for wire ropes. The known lack of ' elasticity ' always associated with drawn wire has long been regarded as significant, and a detailed investigation into the factors governing the magnitude of the plasticity of wires has proved to be of considerable value. This indirect attempt to assess endurance properties of wire has latterly been emphasized by some work on strain behaviour under conditions of cyclic stress.

METHODS OF DETERMINING STRAIN

The conventional single-lever tensile machine is adequate for loading, provided that it is fitted with means for applying the load slowly and smoothly. During the past few years attention has been given elsewhere to the effect of different methods of loading on the shape and nature of the yield point, but as drawn wire does not exhibit the sudden plastic slip associated with yield we are not concerned with these issues.

Devices for the measurement of extension are legion and most of them are useless for work on wire. In many cases the magnification provided is far too small and it is probably for this reason that the erroneous belief has so long prevailed that wire-drawing raises the elastic limit.

Types of extensometers fall roughly into four groups :

(1) Mechanical lever multiplying devices.
(2) Autographic recording attachments to the testing machine.
(3) Optical magnification using a light beam.
(4) A combination of (1) and (3) in which the mechanical magnification is small (usually 2 : 1) and the movement is magnified by a microscope.

Mechanical lever instruments suffer from severe limitation of magnification, although one or two special types have been developed which overcome some of the drawbacks of earlier extensometers.

Autographic recording attachments have slowly developed from the crude arrangements where the points of attachment for measuring the extension were located on the grip heads, to later types where the extension is measured from the test-piece. The extension was usually transmitted to the recording device by strings or tapes whose elastic properties and variation in length with changes in temperature and humidity vitiated the results of high-magnification work. Consequently the magnification was insufficient and the short time employed in producing the curve masked the plastic and creep* effects observable by more refined methods. It is interesting to note that a curve-tracing device which seems to overcome these disadvantages by the use of a synchronized-motor-driven micrometer has recently been developed in America. Fine-wire resistance strain-gauges have not yet been applied to wire specimens, but this method possesses obvious advantages, particularly in connection with investigation of the effect of cyclic stresses.

Optical instruments of the Martens type are capable of measuring very small changes in extension with great accuracy, but difficulties are encountered in attaching the apparatus to the wire specimen.

The Ewing extensometer has been used for most of the work described in this paper. The difficulty of attachment has been overcome by fitting the instrument with very sharp and specially hardened pivot screws which are advanced just sufficiently into the

* The term ' creep ' is used throughout the paper to denote increase of extension under load at ordinary atmospheric temperature. It differs from the creep experienced at elevated temperatures inasmuch as extension diminishes with time.

specimen to support the instrument and then very slightly released before locking in position. With the normal gauge length of 8 in., readings of extension of 0·00002 in. are possible. In practice, an accuracy of 0·0002 in., or one-tenth of the sensitivity of the instrument, is all that is necessary. This extension is equal to a strain of 0·000025, and the significance of readings of this refinement can be judged by the fact that if a 2-in. dia. locked-coil winding rope 1000 yards in length and 12 in. lay is loaded so that the outer wires are subjected to a strain of this amount, the wires lengthen by 1·01 in. The question of whether this is an elastic or a permanent extension is a point of considerable importance in determining the life of the wires in service.

For some of the later work the Lindley dial-gauge extensometer has been used. In this instrument the gauge length is fixed at 2 in., despite which the magnification is of a high order and gives readings of 0·0001 in. Special grips are provided with this instrument for use on wire specimens, but minute hardened steel points have been attached in the centre of the grooves for accurate location and positive attachment to the specimen. This modification has proved quite satisfactory. Figure 1 shows the extensometer attached to a Hounsfield machine ; this arrangement has been found very suitable for stress/strain work on wire test-pieces.

The results can be plotted in several ways. The load/extension diagram obtained by plotting increasing loading against extension of the specimen is not sufficiently informative and is likely to be misleading when comparing wires decreasing in size by increasing amounts of cold work. A better perspective is obtained by converting load and extension to stress and strain ; but a third method, which is a modification of one described by Batson and Hyde,[3] consists of plotting differences between successive extension readings, and this yields curves of great refinement. If the specimen is elastic within the limits of sensitivity of the strain-measuring device, constant load increments will produce constant increments in extension. The difference between each successive extension will therefore be zero, within the limits of the elastic range, and will plot as a straight line parallel to the load ordinate.

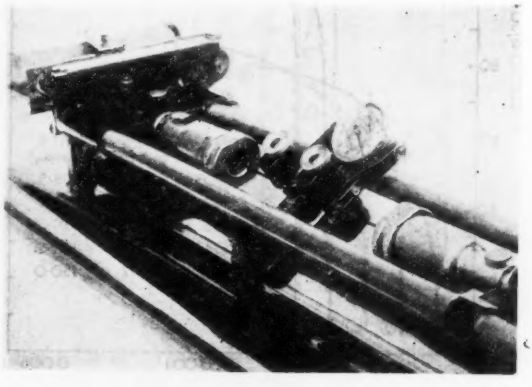


Fig. 1—Tensometer testing machine and Lindley dial-gauge extensometer

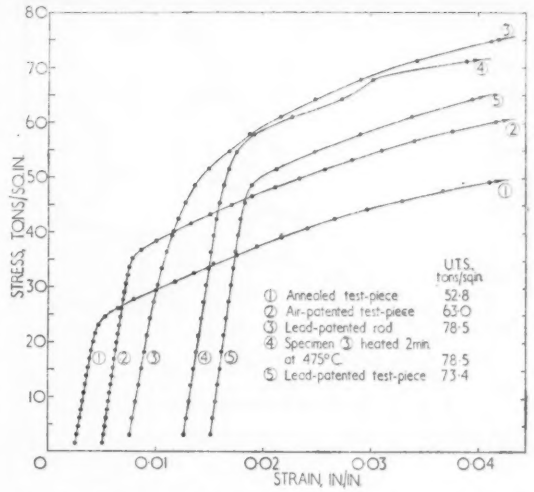


Fig. 2—Stress/strain characteristics of 0·70% carbon steel rod, 0·29 in. dia., showing changes due to patenting

Indication of plastic strain is therefore shown by any deviation from the vertical. Figures 2–5 illustrate these observations, Figs. 3 and 5 being plotted on a strain-increment basis.

CHANGES IN STRESS/STRAIN PROPERTIES DURING PROCESSING

A survey has been made of the effect on stress/strain properties of some of the variables encountered in the manufacture of wire of high tensile strength. Hot-rolled rods may be patented by cooling in lead or air, and the wire produced from these rods may be drawn by heavy or light reductions per pass, depending on the type of plant available ; the total reduction of area may also be varied, depending upon the choice of analysis of the steel. These variations of practice

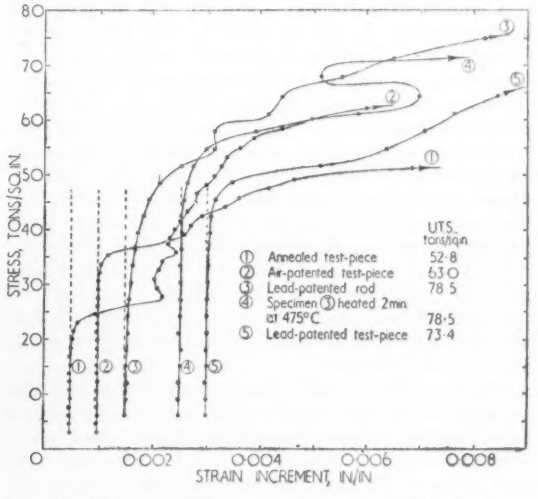


Fig. 3—Observations as Fig. 2, but replotted to show small changes in strain

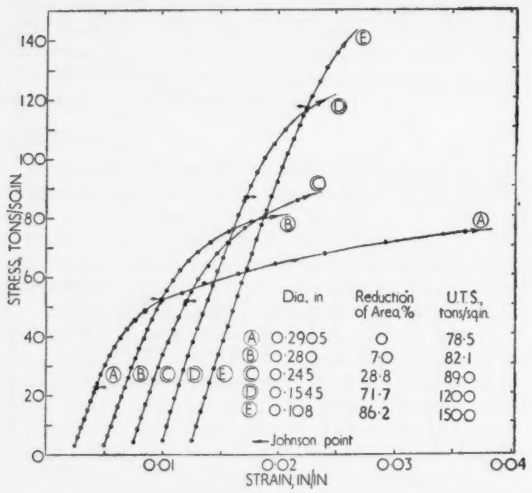


Fig. 4—Stress/strain characteristics of 0·70% carbon steel, lead-patented and drawn in stages to a total reduction of area of 86·2%

cannot be without influence on the properties of the resultant product.

Patented Rods

A length of steel rod of carbon content 0·70%, patented through lead, was removed from a coil for the following tests. To form a basis for comparison, a test-piece was cut to length, carefully straightened, and annealed by heating for 30 min. at 800° C. and cooling slowly in the furnace. Curve 1 of Fig. 2 shows the stress/strain characteristics, and in Fig. 3 the results have been re-plotted by the strain-increment method. The test-piece appears to be elastic over a range up to 20 tons/sq. in., and no clearly defined yield point is observable in Fig. 2. There is, however, some instability in the region of the yield point as shown by curve 1 in Fig. 3, which illustrates the sensitivity of this method of plotting.

A similar straightened test-piece was air-patented by heating for 20 sec. at 1050° C. and then cooling freely in air. The tensile strength was increased by 10 tons/sq. in. and the elastic limit by 11 tons/sq. in., as shown by curves 2 in Figs. 2 and 3. For comparison, a length of the coiled lead-patented rod was straightened and tested without further treatment, and the results are shown in curves 3 in Figs. 2 and 3. These curves have assumed a different form, the marked instability shown in the previous curves having almost vanished, and there is now no clearly defined elastic range. Although curve 3 in Fig. 2 suggests, without close observation, that the rod possesses some elasticity, the strain-increment method reveals a deviation from the vertical ordinate starting with the first loading.

The lack of an elastic range in the coiled rod was assumed to be due to the slight cold work involved in coiling the rod and straightening it again for testing. This assumption was confirmed by repeating the test after submitting the straightened test-piece to a stress-relieving treatment at 475° C. In Figs. 2 and 3, curves 4 show that elasticity has been restored by this treatment and the marked instability in the upper plastic region has returned. There is now an elastic limit at 35 tons/sq. in., although the point appears to be much higher in Fig. 2.

To confirm the plastic condition of a coiled rod, a straightened length from the coil was reheated to the patenting temperature and cooled in lead without disturbing its straightness. The test-piece heated in this manner was, however, slightly curved when cold, and it was necessary to manipulate it slightly for re-straightening. Curves 5 in Figs. 2 and 3 show a marked elastic range, but in Fig. 3 some slight plasticity is shown to have been induced even by the very small amount of work required to render the specimen perfectly straight.

When stripped from the coiling blocks, patented rods are therefore in a plastic condition due to the cold work involved in coiling round the drum, but subsequent baking, which is an essential part of the preparatory treatment for wire-drawing, will restore the elastic condition. Patenting is shown to increase the elastic limit and patenting through lead to yield a considerably higher tensile strength than patenting in air. The conventional yield point is suppressed, but there is a suggestion of plastic instability in the upper plastic range which becomes more marked after a stress-relieving treatment.

Effect of Wire-Drawing

A coil of lead-patented rod, from which the previous test-pieces were cut, was pickled, limed, and baked, and then drawn in a number of stages to yield a total reduction of area of 86%. Samples were selected at stages of 7%, 28%, and 71% reduction of area in drawing to compare the effects of light and heavy reductions. Stress/strain diagrams of these wires, together with that of the patented base, are shown

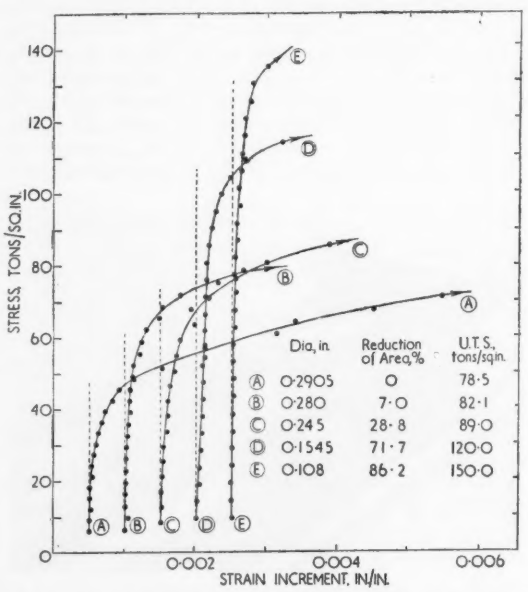


Fig. 5—Observations as Fig. 4, but replotted to show small changes in strain

in Fig. 4. That none of these samples is elastic can be seen by placing a straight-edge along the apparently straight portions of the curves. By replotting stress against strain increments, as shown in Fig. 5, the lack of elastic properties, even in the patented base (curve *E*), is clearly demonstrated.

In a paper dealing with wire ropes for mines, by the Safety in Mines Research Board,[4] the statement is made that rope wire should not be incapable of undergoing further plastic deformation at low loads ; with the possible exception of the curve *E* sample, it will be seen that this condition had been secured in the above test. While a high degree of plastic yield is necessary in the component wires of ropes, such a condition is undesirable, for example, in wires for springs or pre-stressed reinforced concrete. In these cases it is clear that perfect elasticity and a high elastic limit is required. The importance of stress/strain tests in assessing the usefulness of wire for different purposes is therefore emphasized.

Reference has already been made to curve *E* in Fig. 5, and it is interesting to note that the wire from which the test-sample was taken was purposely drawn with an excessive total reduction of area, and because of this its temperature at each pass was considerably higher than normal. The curve suggests that some strain age-hardening has taken place, and the resulting enhanced elasticity confirms the usefulness of this method of production for the manufacture of drawn patent steel spring wire. The influence of low-temperature ageing on the shape of the stress/strain curve is discussed in greater detail later, but it is of interest at this juncture to note the importance of temperature rise during wire-drawing in governing methods of production.

Sintered tungsten carbide dies have made possible continuous wire-drawing, and this has introduced the danger of excessive temperatures in the drawn wire due to cumulative heating from pass to pass. Water-cooled blocks and dies have, however, enabled the temperature rise to be controlled within the range of speeds and reductions of area normally employed.

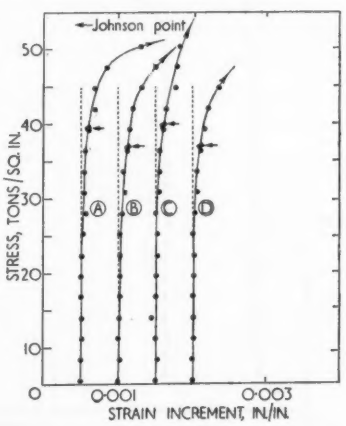


Fig. 6—0·40% carbon steel wire drawn 73% from salt-patented rod to 0·142 in. (U.T.S. 72·0 tons/sq. in.). (A) and (B) drawn 4 passes, (C) and (D) drawn 8 passes

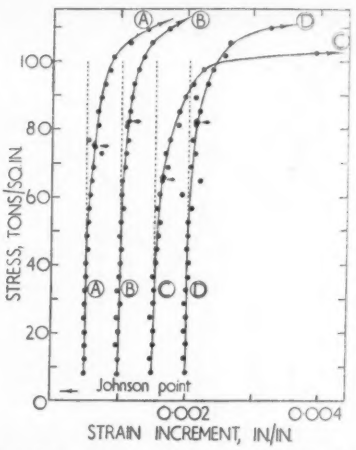


Fig. 7—0·118-in. dia. wire. (A) and (C) drawn 85% reduction, (B) and (D) drawn 75% reduction

Before the advent of continuous wire-drawing, it was the practice to draw rope wire by a large number of passes with a small reduction of area at each pass ; between passes the coils were hung on hooks and allowed to stand for periods of an hour or more during which time some cooling took place. At first sight this might suggest that there was an appreciation of the beneficial effect of limiting the temperature at which the wire was drawn, but the practice was governed entirely by the torsion test to which some steels are peculiarly sensitive in the severely drawn condition. It was generally believed that poor torsions were obtained from heavy reductions and high speeds of drawing, but it is now well known that the cause of low torsion values was the temperature rise in the wires which took place with this method of production in the absence of adequate arrangements for cooling.

It is interesting to compare the stress/strain properties of wire produced by the old methods with similar wire produced on continuous machines. Curves *A* and *B* in Fig. 6 are taken from the front and back ends of a coil of wire drawn with a reduction of area of 73% in four passes on a water-cooled continuous machine. Curves *C* and *D* have been taken from a similar coil of wire drawn with the same reduction in eight separate passes, the coils being allowed to stand and cool between each pass. A close comparison of these curves shows that the effect of adequate cooling on the continuous machine has secured the production of wire with enhanced plastic properties, despite the four heavy reductions, as compared with the eight lighter reductions customary in the old single-block practice.

Figure 7 shows the results obtained from a group of four wires produced for some experimental haulage ropes. Two patented bases were produced in sizes suitable for finishing to a tensile range of 110–120 tons/sq. in., one coil being lower in carbon than the other. The required total reductions were 70% and 85% respectively. These coils were split and one pair was given to a wire-drawer with instructions to produce the finished wire exactly as he would have done a few years ago. The other pair was drawn on

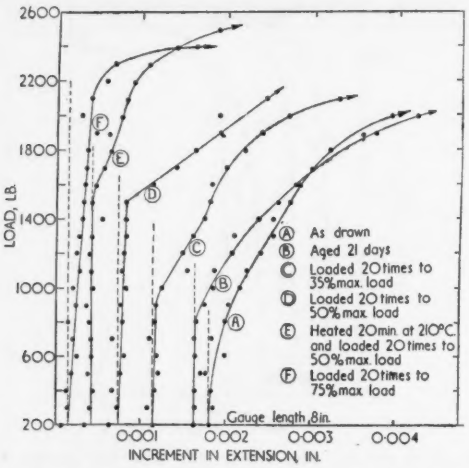

LOAD, LB.
INCREMENT IN EXTENSION, IN.
Gauge length, 8 in.
(A) As drawn
(B) Aged 21 days
(C) Loaded 20 times to 35% max. load
(D) Loaded 20 times to 50% max. load
(E) Heated 20 min. at 210°C. and loaded 20 times to 50% max. load
(F) Loaded 20 times to 75% max. load

Fig. 8—Changes in drawn patent steel wire due to ageing, heating, and repeated stressing

five-hole water-cooled block machines. The wire-drawer used an eight-hole drafting for the 85% reduction and a five-hole drafting for the 70% piece so that the latter coil compares directly with the continuous machine-drawn coil. The resulting curves are shown as *A*, *B*, *C*, and *D*, in Fig. 7, and the Johnson[5] points* are marked for comparison. Sample *A* has been drawn 85% in five passes—an excessive reduction per pass—on water-cooled blocks, and *C* has been drawn 85% reduction in eight single passes, which has lowered the Johnson point. A difference in tensile strength has exaggerated this reduction. The actual figures are as follows :

	Max. Stress, tons/sq. in.	Johnson Point	Percentage of Max. Stress
		Tons/sq. in.	
Five-hole continuous machine	122·6	75·0	61·5
Eight-hole ordinary blocks	112·4	65·0	58

Despite excessive reductions per pass on the water-cooled blocks, the Johnson point has been increased by only 3½% of the tensile range. The samples drawn 70%, *B* and *D*, are almost identical for five-hole continuous drawing and for five-hole single-block drawing, indicating complete control of temperature on the water-cooled blocks. It is surprising to find that the wire produced by a lower total reduction on the single blocks possesses a higher Johnson point than the wire drawn at eight passes and 85% reduction of area, on the same blocks. As the shape of the curves depends largely on the (final) temperature of drawing, these two curves illustrate the variable nature of single-block drawing practice.

Changes Due to Direct Stressing

It has frequently been stated that when an annealed or normalized test-piece is stressed to a point beyond its elastic limit, a new elastic range is induced coinciding with the applied range of stress. It is doubtful whether true elasticity is obtained from one application of such a stress as some cold work has been performed. If a freshly drawn wire is stressed in tension its properties are even more profoundly modified. In order to demonstrate the changes in plastic and apparent elastic properties due to application of direct stresses, a number of load/extension diagrams have been prepared from wire subjected to the following treatments :

Sample	Treatment	Apparent Elastic Limit Tons/sq. in.	Percentage of U.T.S.
A	As drawn	0	0
B	Aged for 21 days	22·4	29·0
C	Loaded 20 times to 35% of U.T.S.	25·1	32·6
D	Loaded 20 times to 50% of U.T.S.	41·8	54·2
E	Heated to 210° C. for 20 min. and loaded 20 times to 50% of U.T.S.	42·5	55·0
F	Loaded 20 times to 75% of U.T.S.	58·6	79·3

The curves are shown in Fig. 8. They demonstrate that the elastic and plastic properties of drawn wire depend on the treatment given during subsequent usage. There is an apparent increase in elastic recovery with increasing stress, but, with the exception of sample *E*, which has been heated to 210° C., none of the samples is strictly elastic within the apparent elastic range. It is clear, therefore, that the repeated application of a direct stress improves, but does not perfectly restore, elastic properties in a drawn wire.

Effect of Heat

The release of internal stresses by heating drawn wire to low temperatures is so well known as to

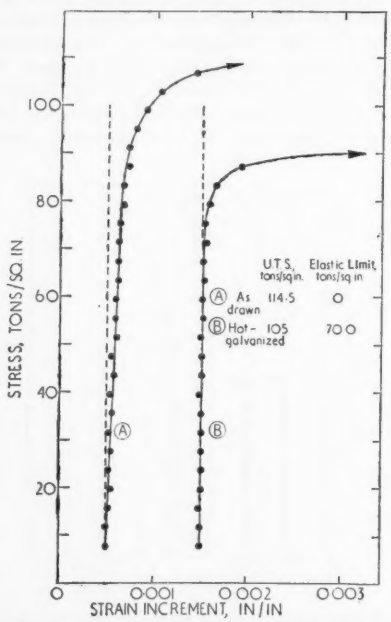


Fig. 9—Effect of hot-galvanizing on elastic properties. Patent steel wire drawn 80% reduction of area in five passes

* In the absence of an elastic limit in drawn wire, Johnson has proposed a definition of the apparent elastic limit as the point on the stress/strain diagram at which the rate of deformation is 50% greater than it is at the origin.

require little comment. Strain age-hardening is induced by heating in boiling water if sufficient time is allowed, and it proceeds with increasing velocity as the temperature of heat-treatment rises. At the galvanizing temperature the change is independent of time. Figure 9 shows complete recovery of elasticity after galvanizing a test-length without coiling or bending. Curve *A* is the drawn wire and curve *B* the hot-galvanized wire.

It is significant that ropes produced from finally hot-galvanized wire are known to yield shorter lives under given conditions than ropes produced from bright-drawn wire of the same tensile strength. Other methods of applying protective coatings are now available which obviate this effect.

Combined Bending and Loading

So far only changes due to gradually applied static loads have been considered, but most ropes are used in a manner involving bending round pulleys, drums, etc., in addition to tensile loading. Conditions of bending under simple static loads are rarely met with and a cyclic system of stresses is usually set up. The effects of cyclic stresses are dealt with in the succeeding section, but it is convenient at this stage to examine the effects of bending a wire round a pulley of relatively large radius whilst it is subjected to a static load.

A number of lengths of wire were pulled backwards and forwards over a pulley by attaching one end to a horizontal reciprocating device and applying a weight to the other end. The pulley had a diameter equivalent to 115 times that of the wire, and the load was equivalent to a tensile stress of 5 tons/sq. in. The wire had a maximum stress of 114·5 tons/sq. in., and the ratio of applied stress to maximum stress was therefore as 1 : 23. Each wire was passed backwards and forwards over the pulley 50 times while under this load, and test-lengths of the same wire were subjected to 20 repetitions of a stress equal to 75% of the maximum stress without bending. Some of these directly stressed wires were subsequently subjected to bending over the pulley.

The results are shown by curves *A* to *D* in Fig. 10. The stress/strain-increment curve of the drawn wire

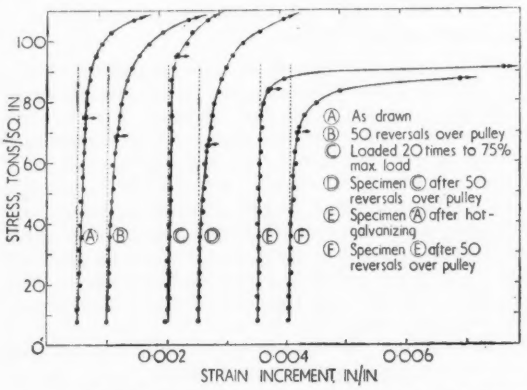


Fig. 10—Effect of combined bending and loading on 0·120-in. dia., 0·60% carbon steel wire

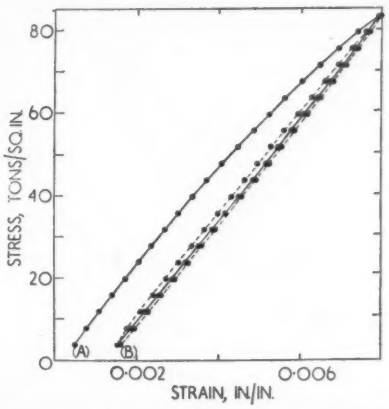


Fig. 11—Changes in extension due to cyclic stresses: 0·120-in. dia. drawn patent steel wire (U.T.S. 114·5 tons/sq. in.), loaded twice to 75% of U.T.S.

A is shown to have been modified by an increase in plasticity after 50 reverse bends over the pulley, as in curve *B*. In the test-length subjected to 20 direct loadings, elastic conditions are very nearly restored, as shown by curve *C*, but when these wires are subjected to bending round the pulley they return to the original plastic conditions as shown by curve *D*.

Similar tests were carried out on a length of hot-galvanized wire. A straight length after galvanizing exhibited perfect elasticity as shown in curve *E*. It was then subjected to the bending treatment described in the previous paragraph, and, as shown in curve *F*, the elastic properties induced by the heat-treatment at the galvanizing temperature have been destroyed.

These changes induced by bending or cold work are of great importance in connection with the behaviour of wires in wire ropes, particularly those used for colliery winding. Pre-formed methods of construction require severe cold work on the wires comprising the strands in order to form them into the lay of the rope. These wires lie dead, that is to say they show no tendency to untwist when the rope is cut ; for this reason they must have been rendered more plastic by bending into shape, and it is probable that some of the improvement in the life of pre-formed ropes is due to this cause.

Cyclic Stresses

The preceding experiments have dealt with the effects of direct loading and with combined loading and bending. Few ropes are used purely in static tension ; the great virtue of flexibility possessed by a wire rope enables it to be used over pulleys and drums, which are essential parts of any equipment used in raising and lowering loads.

The repeated loading and unloading of a rope involves cyclic stresses, *i.e.*, stresses varying between an upper and lower limit. The frequency of the cycle may be low, as in the case of crane ropes, or high, as in the case of a winding rope subjected to shocks at decking. In a smooth wind the load may be taken up rapidly, maintained for nearly a minute, and then released sharply. During these operations the wires

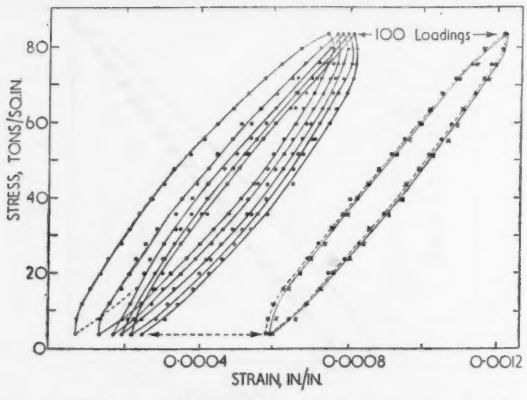


Fig. 12—Effect of repeated loading on 0·120-in. dia. drawn patent steel wire (first loading omitted)

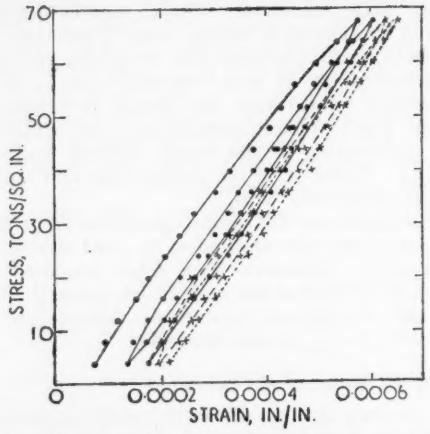


Fig. 13—Stress/strain diagrams of 0·120-in. dia. drawn patent steel wire, loaded and unloaded four times after heating for 30 min. at 250° C., showing reduction in hysteresis

are subjected to bending stresses and these cyclic or dynamic stresses affect the physical properties of the wires in the rope. The changes in strain during these repeated loadings and unloadings are of fundamental importance and they yield a clue to the unique endurance properties of drawn wire.

Figure 11 shows the changes in extension when a test-specimen of high-tensile-strength wire is subjected to two loadings and unloadings to 75% of its maximum stress. Its initial high plasticity is indicated by the permanent set of 0·001 in. per inch of gauge length at (*A*) and (*B*). The second loading and unloading, shown dotted, fails to follow the track of the first removal of the load, and tends to form a loop, which is characteristic of hysteresis phenomena.

In order to see more clearly the plastic-strain behaviour under these conditions of cyclic stress, it is necessary to plot the strain component to a larger magnification. Simple increase in the strain scale introduces difficulties of presentation, and in Fig. 12 the magnitude of the loops has been increased to a scale ten times greater than that normally adopted, retaining the general slope of the curves on the original basis. In this figure the first large permanent set has been omitted and four succeeding cyclic loops showing changes of strain with successive loadings to 75% of the maximum stress are plotted. At each successive load the wire undergoes a permanent set as a result of creep.

Experimental work has been carried out which suggests that creep and hysteresis revealed by drawn wire are not permanent properties but tend to diminish with repeated loadings. The extent to which this occurs after 100 cyclic loadings is shown by the second curve in Fig. 12. In this curve the amount of creep has become very small at each cycle, only two of which have been plotted, and there is now a tendency for the formation of a closed cyclic loop. Hysteresis and creep properties are also markedly affected by tempering (blueing) as shown by the curves in Fig. 13. The very large initial permanent set has disappeared and there is a falling away in creep for each of four successive loadings. The marked reduction in the width of the hysteresis loop is also of considerable significance in connection with the known increase of stiffness in wires treated in this manner.

During the course of this investigation, there was some speculation regarding the hysteresis behaviour of an approximately elastic wire. Specimens were prepared by quenching in oil and tempering back to a tensile strength equal to the drawn wire from which they were obtained. The first loops in Fig. 14 are the result of three loadings on one of these specimens. The amount of permanent set is extremely small at each loading, but there is some hysteresis. In the same figure are plotted identical loadings on the drawn wire, and the great difference in plasticity is very apparent.

The amount of this permanent set and the width of the hysteresis loop are therefore of the greatest importance, as it is these characteristics which permit a cold-worked wire to be bent severely without the skin stress rising to its breaking point. With increasing load, both the permanent set and the hysteresis loops increase in magnitude, and the wire therefore contains within itself the means of relieving severe overstresses which would cause rupture in a perfectly elastic body.

FAILURES DUE TO LACK OF PLASTICITY

Suspension-Bridge Wires

The failure of conventional tests to determine the suitability of wires required to withstand dynamic stresses is shown somewhat dramatically by the now historic failure of the Mount Hope Suspension Bridge, erected between Bristol and Portsmouth, R.I., some 20 years ago. Several months after the cable had been spun, but before the bridge had been completed, fractures were discovered in the wires where the cables had been bent round the shoes of the anchorages. During a period of six weeks after the discovery of these fractures, further wires broke, the number increasing to such an extent that it became necessary to dismantle the partially completed bridge in order to prevent its collapse.

The wire used for the manufacture of these cables differed radically from that normally employed, as

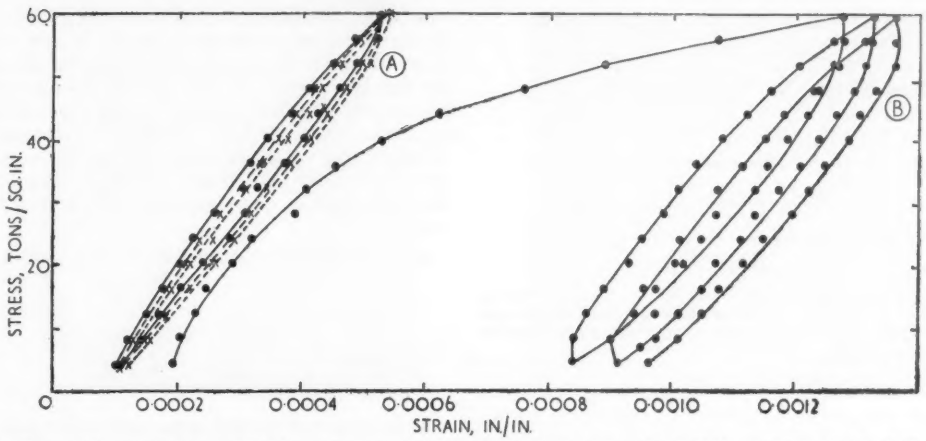


Fig. 14—Comparison of stress/strain characteristics of (A) heat-treated, 0·60% carbon steel, U.T.S. 100·5 tons/sq. in., and (B) lead-patented and drawn steel wire, 0·50% carbon, and U.T.S. 100·8 tons/sq. in. Loaded three times to 60% of U.T.S.

the high-tensile-strength requirements were met by heat-treatment, hardening in oil, and tempering, being followed by galvanizing through molten spelter. Before embarking on this novel method of production, careful fatigue tests had been carried out in comparison with drawn wires of similar tensile strength, and as no significant difference in fatigue properties was observed, some confidence was placed in the departure from normal practice. The curves shown in Fig. 14 illustrate the great difference between the two types of wires, and the curves for the drawn wire must therefore represent a ' pattern ' of cyclic stress/strain properties associated with high resistance to breakdown under combined stress.

It is possible to calculate the extreme fibre strain due to bending from the following formula :

$$E = \frac{d}{2}\left(\frac{1}{R_1} - \frac{1}{R_o}\right) \quad \ldots\ldots(1)$$

where E = strain at extreme fibres, inches per inch.
d = diameter of wires, inches.
R_1 = radius of mandrel, inches.
R_o = radius of curvature of wire before bending, inches.

For straight test-pieces, therefore :

$$E = \frac{d}{2}\left(\frac{1}{R_1} - \frac{1}{\infty}\right) = \frac{d}{2}\left(\frac{1}{R_1}\right) \quad \ldots\ldots(2)$$

The anchorage shoes of the Mount Hope Bridge had a radius of $9\frac{3}{4}$ in., round which was bent wire of 0·193 in. dia., a ratio of 50 : 1. An equivalent mandrel diameter for the wires shown in Fig. 14, 0·120 in. dia., would therefore be 6 in., and from equation (2), $E = 0{\cdot}01$ in.

By extrapolation it is seen that for a strain of this magnitude the stress at the skin of the heat-treated wire exceeds the maximum strength of the material, while for the drawn wire the skin stress is not greater than 60 tons/sq. in. for the same degree of bending. Of greater significance is the effect of fluctuating superimposed tensile stresses. For the drawn wire, each application of stress is accompanied by an increase of strain which effectively maintains a low stress concentration at the skin, whereas the heat-treated wire is subjected to the constant repetition of a stress far exceeding the maximum that the skin of the wire can withstand.

Wire Strand for Use on Railway Signals

The manufacture of wire for railway signals was, until 1943, governed by British Standards Specification 163, first issued in 1934 and revised in 1936. The essence of this specification was a minimum elongation of 12% for the 40–50 tons/sq. in. tensile range. This necessitated the use of a medium-carbon steel in the normalized condition. In addition the specification called for a torsion of 25 twists in a length of 100 diameters.

During the period in which this specification was applied, a considerable number of failures occurred, nearly all of them at loops spliced on to the ends of the strands. A typical case is shown in Fig. 17 where most of the fractures are of a fatigue type, the remainder having broken in tension because of their inability to sustain the increased stress thrown upon them. This type of failure was so typical that considerable work in connection with fatigue properties was undertaken. Microscopic examination close to the fatigue fractures quite commonly revealed the presence of numerous creeping fatigue cracks, a typical example being shown in Fig. 18. In case the microstructure shown should be misleading owing to its apparent cold-worked condition, it should be pointed out that the normalizing of wires prior to galvanizing is carried out continuously, using lead as a heating medium, the temperature rarely exceeding 730° C. At this temperature and with the high rate of travel through lead, the elongated pearlite of the drawn wire does not revert to its normal condition.

Fatigue tests of these normalized wires tend to be lower, although not markedly so, than wires of similar tensile strength in which the strength is obtained by cold work. A typical examination was made on two wires : No. 1 was drawn to the required tensile strength and finally hot galvanized, and No. 2 was drawn to size from a higher-carbon steel and then normalized through molten lead at a temperature of 730° C. The results, which are as follows, show that there is a difference in tensile strength between the

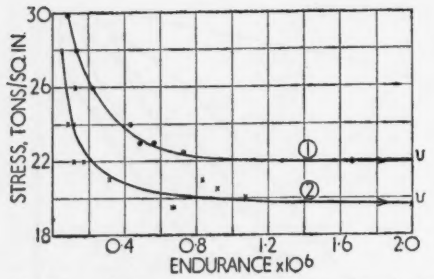


Fig. 15—Stress/endurance curves of signal strand wires: (1) Drawn to the required ultimate tensile strength, and (2) tensile properties obtained by heat-treatment

two wires, but the ratios of fatigue stress to ultimate stress are not markedly different ; endurance curves obtained on the Haig-Robertson machine are shown in Fig. 15 :

Analyses of Wires, %

	No. 1	No. 2
Carbon	0·14	0·34
Silicon	0·121	0·144
Sulphur	0·038	0·033
Phosphorus	0·032	0·033
Manganese	0·45	.0·75

Physical Properties

	No. 1 (Drawn and Hot-Galvanized)	No. 2 (Drawn and Normalized)
U.T.S., tons/sq. in.	51·4	44·4
Elong. on 10 in., %	6·65	12·25
Torsions in 100 dias.	17	37
Bends over 5 mm.	12	23
Limiting fatigue stress, tons/sq. in.	22·0	19·7
Ratio of fatigue stress to ultimate stress	1 : 1·17	1 : 1·13

Since fatigue tests taken in this manner yielded no clue to the unsatisfactory nature of the normalized material when subjected to fatigue conditions, the load/extension properties of the two types of wires were examined and the results fall into line with work previously described. In Fig. 16 are shown typical curves in which the marked elastic range of the normalized wire is in direct contrast with the plastic properties of the drawn wire. The high elongation of the normalized wire, to which in the past much importance has been attached, is shown to occur at a comparatively low load and obviously offers no safeguard against conditions of overstress. In this respect there is a close analogy between the heat-treated wires which failed on the Mount Hope Suspension Bridge.

Eventually, full-scale trials of signalling strand, manufactured from drawn wires, were carried out in conjunction with one of the main-line railways, a site being chosen where many failures of the type shown in Fig. 17 had occurred. After the lapse of some time it became evident that the drawn wires were standing up to the highly stressed conditions of this location and the strands were maintained in service for an indefinite time without any suggestion of fracture at the loops.

In view of this experience the British Standards Specification was revised and the revolutionary step was taken of imposing a maximum elongation in place of the previous minimum of much higher value, in order to ensure the supply of nothing but drawn wire for this purpose. In the revised specification the torsion test was eliminated as it apparently had served no useful purpose, but a bend test was offered in substitution. The essential figures from the two specifications are as follows, and Figs. 19 and 20 show the difference in microstructure of the two types of wire :

17-S.W.G. Galvanized Steel Wire for Signalling Strand

	B.S.S. 163 —1936	B.S.S. 163 —1943
Designation	W.S.2.	W.S.2.R.
U.T.S., tons/sq. in.	40–50	50–60
Elong. on 10 in., %	12 (min.)	7 (max.)
Torsions in 100 dias.	25 (min.)	...
Bends over 5 mm.	...	15 (min.)

It is noteworthy that since this revision no single instance of fatigue failure of the type shown in Fig. 17 has been reported in strands containing wires produced to the new specification.

Core Wires in Locked-Coil Winding Ropes

Regulations require that colliery winding ropes shall be recapped every six months, a length of not less than 6 ft. being cut off on each occasion. Examination of the lengths cut off frequently shows evidence of serious deterioration due to fatigue failures, and this is particularly so in the case of locked-coil ropes, those from deep shafts apparently being most affected A photograph of the 17-wire layer from one of these ropes is shown in Fig. 21 ; fatigue breaks unaccompanied by surface deterioration are clearly shown. In view of this rapid break-up at the extreme end of the rope, it has been argued that this portion of the rope is subjected to the most severe stresses. It is difficult to appreciate the force of this argument, particularly in the case of deep winds where the weight of the rope, together with the accelerating force, must impose a considerably greater stress in that portion

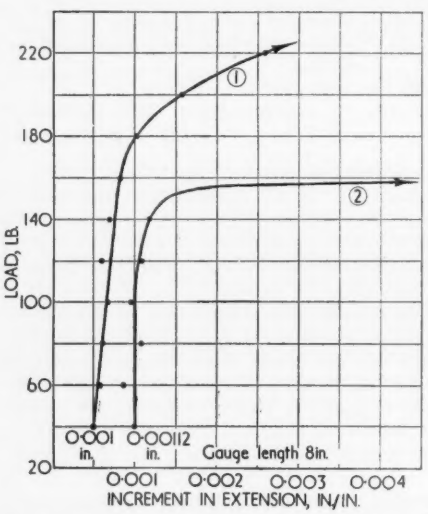


Fig. 16—Load/extension curves of the same wires as Fig. 15

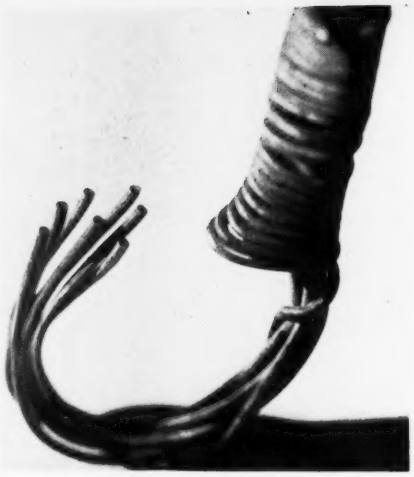


Fig. 17—Fractured signal strand loop, showing fatigue breaks

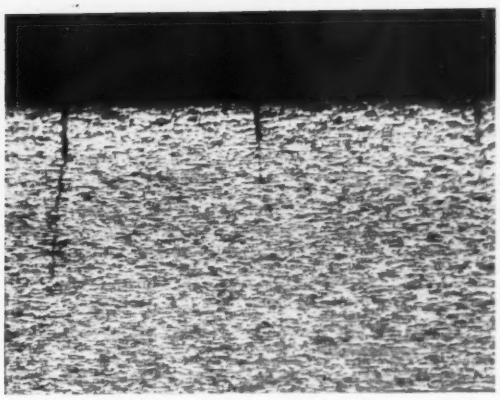


Fig. 18—Longitudinal section of the signal strand wire shown in Fig. 17, showing fatigue cracks close to fracture

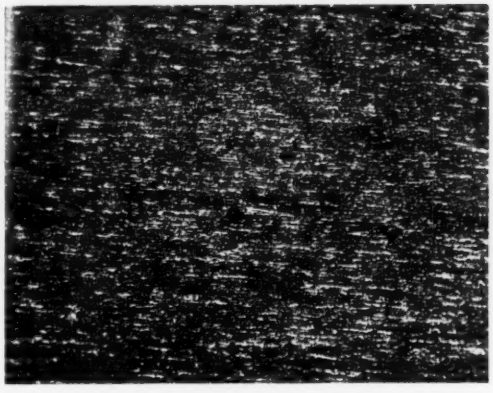


Fig. 19—Microstructure of heat-treated signal strand wire

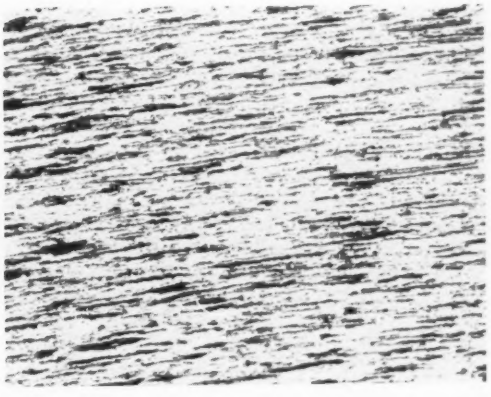


Fig. 20—Microstructure of hard-drawn mild-steel signal strand wire

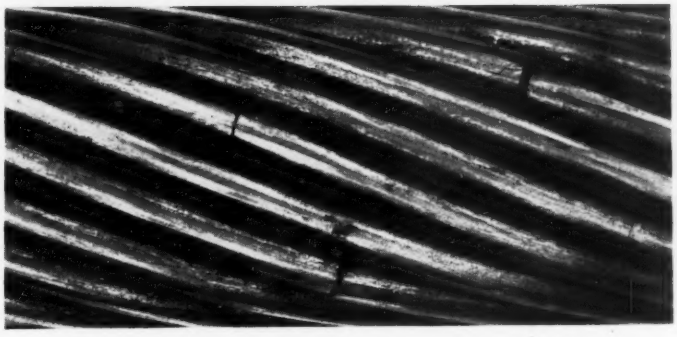


Fig. 21—Fatigue failures in the core of locked-coil winding rope

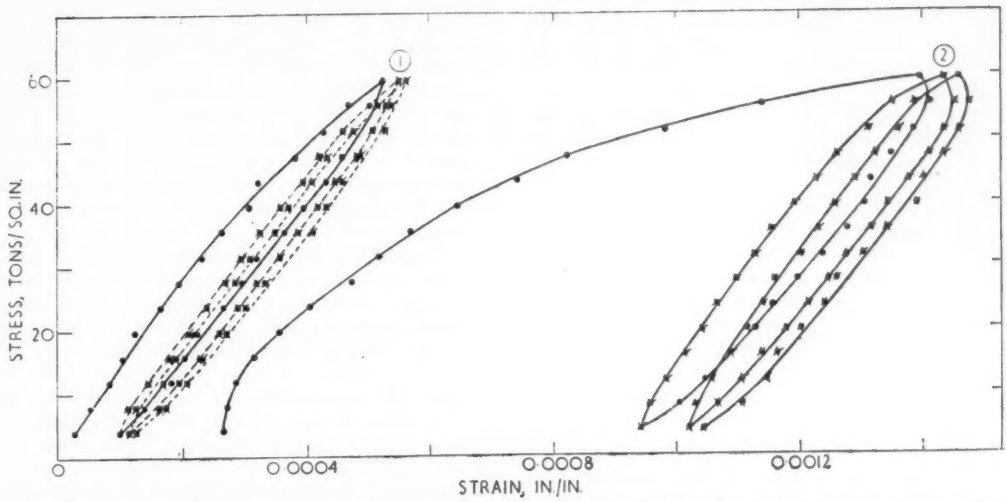


Fig. 22—Comparison of stress/strain characteristics of the same wires as Fig. 14, but after subjecting to 50 reversals over a pulley

of the rope immediately under the pulley when the cage is being picked up from the pit bottom.

The work described in this paper would suggest that there may be another explanation for the fatigue failures of wires at the free end of these ropes. If curves *C* and *D* of Fig. 10 are examined in conjunction with the curves of repeated loading in Fig. 12, it will be seen that the repeated application of stress in direct tension destroys the property of plastic creep exhibited by a drawn wire and materially reduces the width of the hysteresis loop. If, however, the wire is subjected to further internal cold work by bending under tension, then the capacity for plastic creep is restored.

Fatigue failures of the type shown in Fig. 21 are less frequently met with in the length of the rope subjected to bending round the pulley and drum. As during this period the wires are being overstressed not only by bending but also by the direct stress set up by the accelerating force acting on the full length of the rope, it is somewhat surprising that this portion of the rope does not deteriorate more rapidly than the free end. Some significance must, therefore, be attached to the effect of bending in maintaining wires in a plastic condition. The free end of the rope, which is subjected to direct stresses only, can be expected to become elastic in service and in consequence liable to the type of fatigue normally discovered.

Unfortunately it is impossible to obtain direct information of stress/strain characteristics from wires that have been stressed in service, owing to the fact that the manipulation required to straighten out the lay before testing completely modifies the stress/strain properties. It is, however, of interest to observe the behaviour of the heat-treated wire and of the cold-drawn wire of Fig. 14, when they are subjected to repeated bending while also under a direct stress. These wires were given 50 reversals over a pulley of a diameter equal to 115 times that of the wire, the load at the end being equal to a tensile stress of 4·5 tons/sq. in.

The results of three successive direct-stress cycles after this treatment are shown in Fig. 22. The heat-treated wire has taken on a slight permanent set and there is now evidence of creep at successive loadings. The marked plastic properties of the drawn wire have not been affected materially by this treatment,

Table I

VALUES OF PERMANENT SET, HYSTERESIS, AND RATE OF CREEP AFTER VARIOUS TREATMENTS

No. 1 was loaded to 75%, and Nos. 2 to 6 to 60%, of the ultimate tensile strength

No.	Condition of Test-Piece	U.T.S., tons/sq. in.	Permanent Set at 1st Stress Cycle, in./in.	Hysteresis at 3rd Stress Cycle, in./in.	Rate of Creep at 3rd Stress Cycle, in./in.
1	0·60% carbon, as drawn	114·0	0·00105	0·000181	0·000038
2	Specimen heated for 30 min. at 250° C.	112·0	0·000062	0·000042	0·000018
3	0·60% carbon, oil-quenched and tempered	100·5	0·000010	0·000042	0·000008
4	Specimen 3, after 50 reverse bends round pulley	100·5	0·000073	0·000052	0·000011
5	0·50% carbon, as drawn	100·8	0·000645	0·00014	0·000049
6	Specimen 5, after 50 reverse bends round pulley	100·8	0·000678	0·00011	0·000025

although there is a suggestion that the creep rate might fall off with further loading.

It is noteworthy that the method of production of wires for locked-coil ropes has, of recent years, been modified with a view to increasing plasticity, and there is some evidence that capel-end fractures are now not so prominent a feature as they were some years ago.

In Table I are given some values of hysteresis, permanent set, and rate of creep, for wires subjected to the various treatments outlined in this investigation. The reduction in both creep and hysteresis resulting from heating drawn wire at a low temperature is most significant, as this treatment is frequently used to induce stable properties in drawn wires after manufacture into springs and similar parts where permanent elastic properties are required.

Wires for Pre-Stressed Reinforced Concrete

Shortage of timber and steel for constructional purposes has led to important developments in the production of beams, railway sleepers, and similar parts in which severely drawn steel wires are incorporated. These wires are pre-stressed up to 70% or more of the ultimate tensile strength, and stable elastic properties are required in the wires if the strength of these concrete structures is not to deteriorate. Tentative specifications for the component wires have attempted to assess this condition on the basis of a proof stress, but at the outset difficulty has been experienced in defining a form of test suitable for use with freshly drawn wires.

Reference to Figs. 8 and 14 will show that proof-stress determinations, particularly those involving permanent set when the load is released, are of little value owing to the change of properties effected by this treatment. As the tests recorded in Fig. 14 reveal, an imperfect elastic condition is conferred on a drawn wire by loading, the range becoming equal to the range of stress applied. Figure 12, however, shows that repetitions of stress of the order of one hundred are required before almost perfect elasticity is obtained. The work described also shows that complete elastic stability is obtained only by heat-treatment at a low temperature and that, should heating be preceded by loading, a true elastic limit equal to the applied load is induced.

CONCLUSIONS

(1) Wire as-drawn possesses no elastic properties and therefore has no elastic limit.

(2) The unique ability of drawn wire to withstand the repeated application of combined bending and tensile stresses is shown to be due to its capacity for plastic creep associated with hysteresis behaviour of a high order. Wires of high tensile strength produced by hardening and tempering are shown to possess negligible creep characteristics and greatly reduced hysteresis. Such wires have proved to be unsuitable for use under conditions involving dynamic stresses.

(3) Simple ageing and accelerated ageing by heating to a low temperature restores the elastic range almost completely. Partial elastic stability is conferred on wires for use in pre-stressed reinforced concrete construction by the application of a high initial load, but more than one loading is necessary for complete stabilization to be effected. Attempts to assess the suitability of drawn wires used for this purpose by means of a proof test are misleading owing to changes in plastic properties introduced when the test-piece is loaded. If wires stabilized by either of these methods are bent round a pulley or otherwise manipulated, the elasticity conferred by the treatment is destroyed.

(4) Whether wire should be drawn by a small or a larger number of passes depends merely on the temperature developed by passage through the die and retained by the wire on the block. In the absence of special cooling arrangements a larger number of passes will produce a more plastic wire. The limit of speed in wire-drawing is therefore resolved into the question of how rapidly the heat generated in drawing can be abstracted from the wire, or in other words, the degree to which the temperature rise can be restricted. Consequently efficient cooling on intermediate blocks in continuous wire-drawing is of paramount importance.

(5) From these investigations the inference is drawn that :

(1) High plastic and hysteresis properties are essential for a durable rope wire.

(2) As these properties are impaired by rise in temperature of wire during drawing, future progress of the art must be along lines of complete suppression of temperature rise in the wire immediately it leaves the drawing die.

Acknowledgments

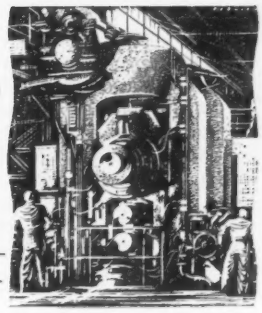
The author would like to express his thanks to the Chairman and Directors of Messrs. Rylands Brothers, Ltd., and the Whitecross Co., Ltd., Warrington, for permission to publish this paper. Thanks are also due to Lt.-Com. G. K. Rylands for his great interest and counsel during the course of the work, and to Mr. Bernard Ryan for carrying out a number of the tests with great skill and patience.

References

1. E. T. Gill and R. Goodacre : *Journal of The Iron and Steel Institute*, 1934, No. II, pp. 293–317.
2. W. H. Swanger and G. F. Wohlgemuth : *Proceedings of the American Society for Testing Materials*, 1936, vol. 36, part 2, pp. 21–75.
3. R. G. Batson and J. H. Hyde : " Mechanical Testing." London, 1922 : Chapman and Hall, Ltd.
4. Safety in Mines Research Board : " Wire Rope for Mines," p. 32. Paper No. 41. London, 1929 : H.M. Stationery Office.
5. Johnson : " Materials of Construction," p. 10. New York, 1918 : John Wiley and Sons.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



Continuous Steel Strip Pickling

By R. W. Treasure

SYNOPSIS

The paper deals with the general principles of construction and operation of the modern continuous-strip pickle line. The history of the development of the plant is outlined, and a general description is given of the results of investigation into the process involved in the removal of mill scale by the use of sulphuric acid liquor.

A description is also given of the procedure in electrolytic pickling, and a reference is made to the semi-continuous type of pickler, and also the rotary-coil type pickle line.

The processing of stainless steel with the aid of caustic soda is dealt with, a further description being given of the mechanical equipment, with its general design and method of operation.

Reference is made to the practical considerations, both from a constructional and operational aspect, of the continuous wide-strip pickle line, consideration being given to acid strengths and acid tank construction, and also the exhaust-fume scrubbing equipment.

THE term "pickling" is given to the process of removing oxide scale formed during the hot-rolling operation.

For the production of steel strip, either for sheets or tinplate, the intermediate step between the hot- and cold-rolling process is the continuous pickling operation. It is a well-known fact that all hot-rolled material to be cold reduced requires pickling, and this has led to considerable importance being placed on the pickling process ; in fact, it is rapidly becoming a precision operation.

In this paper are discussed the various methods for processing carbon steel and stainless steel before cold rolling.

HISTORICAL SURVEY

A review of developments leading to the modern practice of pickling with dilute sulphuric acid will be of interest. The history of the process indicates that the use of sulphuric acid was not adopted until 1806, when production was on a scale permitting its use at low cost.

Early accounts of its use have been given in papers published in 1818, and in 1829 Morgan, in this country, patented the use of sulphuric acid. Steam-heated pickling baths were used in 1850, a patent was taken out in 1863 for pickling machines, and in 1870 pickling machines superseded hand labour. From this date until 1910 developments were mainly confined to mechanical advances.

The increase in demand for cold-rolled steel products called for rolling mills of improved design, with the attendant necessity for changes in the handling of material. The pickling machines thus became known as batch picklers. In these years of development of the rolling and pickling of narrow strip the material was pickled in coil form. The strip as delivered from the mill was approximately 8 in. wide and was prepared for coiling by a recoiling process. These coils, after being placed in special racks, were immersed in baths of hot dilute sulphuric acid similar to the present plunger type of plant, and were subsequently washed in cold, and then hot, water. These methods were inefficient and resulted in a very unevenly pickled surface.

In 1913 a continuous strip pickler was developed to process strip approximately 8 in. wide. For this purpose a number of strands of strip were run parallel to each other through a single tank of acid, this being the first of the multi-strand type of lines. The material was fed through the tank from a series of staggered feed racks at the entry end, the individual coils being placed horizontally on each rack, and each strand was paid out by hand after being joined to the end of the preceding strip. The material travelled horizontally through one acid tank, a rinse tank, and a dryer, and was then coiled on a reel. The coiling reel was the only source of power for pulling the strip through the tanks. The method of joining the ends of the strip was to punch a hole in the end of each coil and connect the ends of the strip by placing a double hook through the holes, this being held in position by the tension of the strip. These hooks were removed at the exit end of the line before recoiling.

With the demand for increased width of strip the number of strands passing through the tank decreased,

Manuscript received 28th February, 1949.

Mr. Treasure is Engineering Executive in the Auxiliary Rolling Mill Dept., of the Wellman Smith Owen Engineering Corporation, Ltd.

until, between 1920 and 1930, it was the practice to pass a single strand through the unit.

It was about this time that coil boxes for uncoiling the strip were introduced. The pickling solution was maintained at 10% concentration by weight and held to a temperature above 180° F. by means of steam. The tanks were constructed of timber. By 1926, developments, particularly in America, had reached a stage that permitted the handling of a strip up to 36 in. wide, and this, together with the improvements in mechanical equipment, gave rise to a line consisting of a coil box for uncoiling, pinch rolls, upcut shears, four wooden pickling tanks, water-quench tanks, dryer, upcut shears, and a three-roll upcoiler. The weight of hot-rolled coils from the mills had increased to between 3500 and 4000 lb. The strip was uncoiled, and the connection was still made by means of holes punched in the ends of the strip and the locking pins. These were **U**-shaped with a hammered head, so that as the strip passed through the pinch rolls the pins were flattened. Several pins were used across the width of the strip. The upcut shear at the entry end was used to square the ends. After its passage through the pickling and rinsing tanks, the strip was dried by hot air and the joined ends were cut off. The strip was then coiled in the recoiler and removed for further processing.

The tanks, which were built from timber, were lead lined. The pinch rolls were of steel, and the strip-carrying rolls were first constructed of wood and then grey iron. The line speed ranged from 50 to 150 ft./min. This plant operated successfully, and, together with further developments in rolling and pickling technique, other pickle lines were installed in America. These consisted principally of a coil box, pinch roll, a stitcher for joining the coils, four pickling tanks, rinse tanks, dryer, upcut shears, and recoiler. The use of a stitcher for joining the ends of the strip, and the use of an exhaust system, with attendant improvements in tank construction, were the main features of these lines.

The stitcher unit consisted of a punching mechanism driven by an electric motor through gearing, which punched slots spaced across the width of the strip. The two ends of the coils were overlapped and the punch was then operated. A narrow light-gauge steel strip was then woven through the slots, which were flattened as the strip passed through the pinch rolls.

The use of an exhaust system to remove the pickling fumes was a unique feature of this installation. Before this time the pickling department of any mill was an undesirable place in which to work, owing to the objectionable steam and acid fumes. With this exhaust equipment it was necessary to fit covers on the tanks, and these, together with the exhaust-fume ducting, were lined with lead. A further improvement in pickling equipment at this time was the use of steel tanks of large size. Demands for even wider strip were being made, and it is on record that at about this time tanks were produced to accommodate material up to 72 in. wide with a tank length of 60 ft. and a depth of 4 ft. 6 in. Tanks of these dimensions obviously gave rise to problems in connection with the acid-resisting lining. Since lead was the only acid-resisting material known at that time this metal was used, and gave satisfactory results after increasing the thickness of the lead and lining the tank bottom with acid-resisting brick. It was by now appreciated that continuous cold rolling and pickling of wide material was a commercially sound proposition, and a large number of plants were installed between 1930 and 1937 in America. At this time projects were afoot in this country for the installation of two wide-strip continuous pickle plants.

With increased mill speeds it was obviously necessary to increase the capacity of the pickling equipment, and between 1932 and 1936 considerable advances were made in America in handling equipment and also in the use of: (*a*) A scale breaker to crack the scale, (*b*) a looping pit for accumulation of strip while feeding in a fresh coil and joining the ends, and (*c*) a steel tank with rubber/brick lining. A further development was a flash butt welder for joining the end of the coils—now standard practice in all modern continuous lines. The use of flash butt welding has been developed even further, and welds are now made which can be passed through the cold reducing mill; thus large capacity coils are favoured, as they considerably reduce the handling time on the cold mill.

One of the major problems that had to be solved in the development of these pickle lines was that of tank construction. Progress from wood and steel-lined tanks to rubber-lined steel tanks was not gradual, but was a revolutionary step to the tank manufacturers. Rubber-lined steel tanks were not new in pickling plants of smaller capacity, but such linings were not well adapted to the requirements of a large tank approximately 60 ft. long, 8 ft. 9 in. wide, and 4 ft. to 5 ft. deep. Hard rubber available at that time could not withstand the effects of impact or expansion and contraction with changes in temperature. Since hard rubber was not suitable for this application, softer rubber was suggested, but this had distinct disadvantages which limited its use, one of these being the ease with which it was cut and gouged by the strip.

In order to overcome these problems, a lining had to be designed which would have the advantages of both hard and soft rubber. This lining was comprised of a layer of hard rubber, cushioned between two layers of resilient soft rubber—all three layers being vulcanized together to form an integral structure with the steel surface. This structure offered improved resistance to impact and damage. The rubber lining, together with the acid-proof brick surfacing, and the inclusion of expansion joints to prevent the buckling and cracking of the walls, did much to improve operating conditions, the brick lining being particularly useful as a heat insulator and reducing the temperature on the rubber surface. This type of tank construction has proved entirely satisfactory, and is used on the majority of lines at the present time.

With the demand for increased production, joining of the coil ends by welding was tried out in America to reduce the time required and to build up large coils with welds of such nature as to allow them to

pass through the cold mill. The flash butt welder proved to be most suitable for this service.

The continuous operation of a plant of this type has demanded considerable advances in electrical equipment, and it has been possible for the interlocking of the various units in the pickle line to be accomplished. The following are descriptions of the various forms of pickling which are in more common use in steelplants today.

ELECTROLYTIC PICKLING

In the early stages of development in America with this type of plant, the electrolytic equipment was used in Nos. 2 and 3 tanks of a continuous pickle line. The system used alternating current with the strip passing between, but not touching, the electrodes. By passing an alternating current between the primary electrodes, each side of the strip became alternately cathodic and anodic, so that both sides of the strip were pickled alike. For the installation in question, the primary electrodes were made of 8% antimonial lead, having embedded copper bars for better distribution of the current. Six top and six bottom electrodes were used in each tank, these being 6 ft. 6 in. long with width proportional to tank width. The bottom electrodes, formed of a $1\frac{1}{2}$-in. thick rolled lead sheet, rested on the bottom of the tank, flush with the top of the brick lining. Brick piers were arranged to protrude through the lead to support the strip. Four copper bars, covered by lead sheathing, conducted the current to the bottom electrode. Owing to the difficulty encountered from lead being deposited on the surface of the strip, electrodes fabricated from graphite slabs were studied.

A current supply of 6600 V., 3 phase, 25 cycles, was brought to a bank of two single-phase transformers, connected to give 440 V. single-phase power, which led to low-voltage transformers located adjacent to the line. Each tank had a 225-kVA. single-phase 440/15–7 water-cooled transformer, these being placed near to the tanks, in order to keep the low-voltage leads as short as possible. The concentration of sulphuric acid used was 10% by volume, and the temperature was maintained at 190° F. by the current. The installation resulted in an average increase of 35% in production speed.

In using this type of plant, however, it must be borne in mind that the speed of a line depends on the handling time at the entry end, and therefore the electrolytic pickler will only prove an advantage when using large coils.

SEMI-CONTINUOUS PICKLER

The semi-continuous type of pickling plant utilizes the inherent flattened stiffness of hot-rolled strip, each coil being passed through the line individually. A schematic arrangement of this type of plant is given in Fig. 1. The hot-rolled coil is placed in a coil-feeding machine and the leading end is fed into a pinch-roll unit, so arranged that the rolls can be rapidly opened. A strip is then passed into a roller leveller, which in turn feeds the strip into a preheat hot-water tank which raises the temperature of the coil to that required for pickling. With the use of synchronized pinch rolls the strip is then fed into the acid tank, the bottom of which has a special contour to support the strip. By the use of further synchronized pinch rolls the coil is passed through a cold-rinse tank, hot-rinse tank, and a dryer, and so on to the final coiler.

ROTARY-COIL TYPE CONTINUOUS PICKLER

The rotary-coil type continuous pickler was developed in order that hot-rolled loose coils could be processed without the necessity for unwinding the strip. The loose coils are rotated on a mandrel in their passage through the pickle and wash tanks. The method of handling is as follows.

The coil is passed through a special scale breaker, normally a separate unit from the line, and is rewound. Special equipment is provided on the tension reel on the scale-breaker line in order that the coils can be back-wound to a given outside diameter so that an air space can be obtained between the turns of the coil. This loose coil is positioned in front of a coil-lifting mechanism which raises the coil into a cradle, allowing a mandrel to be inserted through the bore of the coil. Both coil and mandrel are then conveyed by means of a fork carry-over mechanism to the preheating tank and lowered. When the mandrel is released from the carry-over mechanism, sprockets engage with a roller chain and rack, and by this means the coil is carried through the tank and rotated while completely submerged. When it has passed through the tank, the coil is transferred to the following tank by means of a further mandrel and fork-type carry-over mechanism. When the material is passing through the acid tank only approximately two-thirds of the coil is submerged, the rotation keeping all parts of the coil in contact with the pickling solution. Further transfers are made through the respective tanks by further carry-over equipment.

CAUSTIC SODA PICKLING EQUIPMENT

Before describing the more conventional type of acid continuous pickle line, it would be as well to add a brief description of a type of plant which has been more recently developed, and which is now receiving serious attention in this country. The plant employs a process of descaling by means of molten salts, the use of which has largely followed from the rapid progress made in America in the last few years. Two processes are in use, which, although similar in many respects, differ in fundamental principles. Before describing each process, consideration of the common features of each will be helpful, and will enable a comparison to be drawn with the conventional acid pickle line.

The main feature of molten-salt descaling is the rapid removal of oxide scale in a medium that has no positive action on the parent metal. The rapidity of action is more pronounced with such refractory oxides as those of the stainless and heat-resisting steels, and it was for this class of material, which has always proved difficult in acid pickling, that the process was first designed.

With plain carbon and low-alloy steels, the reduction in descaling time, when compared with acid pickling, is not greatly marked, but it is nevertheless pronounced, and this, together with the elimination of metal wastage, gives the process certain advantages. With the elimination of metal wastage, absence of pickling embrittlement naturally follows, and has a certain importance in any further processing.

In both processes a bath of molten caustic soda containing active ingredients is used, the ingredients and temperature of the operation being different in each case.

The material to be descaled is immersed in the bath for a period of time depending upon the section, the nature, and the weight of the scale, two to twenty minutes being normal. The chemical reactions involved convert the scale to a finely divided, loosely adherent deposit, which is rapidly removed in the subsequent stage—a cold-water quench, followed by, where necessary, a short immersion in a warm dilute acid.

A brief description of the two processes follows.

SODIUM HYDRIDE PROCESS

The sodium hydride process involves the use of a bath of molten caustic soda, enriched with sodium hydride in a concentration of about 2%, operating at a temperature of 350–370° C. The sodium hydride, being an active reducing agent, reduces the oxide scale either direct to the metallic state, or, as in the case of the chromium steels, to a lower oxide, and in any case to a finely divided deposit. This deposit is largely removed by the shattering effect of steam produced in the subsequent cold-water quench. In this condition the material has a dull mat finish which is satisfactory for most purposes, and a further hot-water rinse is all that is required to remove any excess caustic soda. For bright work, however, the practice is to follow the soda immersion with a short acid dip in dilute sulphuric acid, dilute nitric acid, or dilute nitric acid with minor additions.

The reduction of the oxide scale by the sodium hydride results in the formation of more caustic soda, and the amount of caustic formed is sufficient to compensate for drag out by the strip. The sodium hydride itself must be continually replaced, and this is accomplished in specially designed generators, of which there may be one or more, depending on the size of the bath. Sodium in the form of bricks is fed at intervals through a removable lid on the generator, and the hydrogen from an ammonia cracker is led in through a pipe, the end of which is below bath surface level. The hydrogen bubbles up to meet the now fluid layer of sodium, and the sodium hydride thus formed disperses evenly throughout the bath.

THE EFCO-VIRGO PROCESS

The Efco-Virgo process also uses a bath of molten caustic soda, but the operating temperature is 480–540° C., depending upon the type of alloy, and the ingredients are mainly of an oxidizing nature. The chemical conversion of the scale is accompanied by volume changes which are such as to produce loosely adherent by-products which are soluble in a weak acid. The soft by-products are largely expelled by the shattering effect of the steam produced in the cold-water quench tank. The quenched material has again a dull grey finish which is satisfactory for inter-process work where the deposit has been found to act apparently as a lubricant in further process operation. For really bright work, however, it is again necessary to follow with a short immersion in weak acid, or alternatively, and depending upon the finish required, the acid step may be in two stages, *viz*: (i) 10% HCl at 75–80° C., (ii) 10% HNO_3 at 75–80° C. The time required in the salt is again from two to twenty minutes, giving an overall time cycle of something like five to twenty-five minutes, this, of course, depending upon the material being handled.

As caustic soda is not a by-product of the reactions occurring, replenishments to compensate for drag-out are necessary, 7–9 lb. per ton of work treated being normal. The salt, however, is self-regenerative, as the oxidizing agents which convert the scale are themselves progressively reconverted to their original state by action of the atmospheric air. For this reason the bath depth/area ratio is important.

PLANT REQUIRED

The plant required for both processes is comparatively simple. The bath containing the caustic soda is of conventional design, having a welded mild-steel pot. The welding, which is preferably done by electric arc, is important, as it must ensure full penetration of sound weld metal on all joints. After welding, the pot must be stress relieved. The bath may be heated externally or internally, but it is obviously more efficient to arrange for internal heating, as there is no thermal lag from pot to salt, and maximum pot life is assured. The comparison between internal and external heating is more pronounced when considering the shorter time cycle experienced in internally heated baths of the immersed electrode type. The reduction in descaling time is also found to be more pronounced with increasing size of bath. This is no doubt because of the circulatory motion of the salt caused by the electrodynamic forces operating around the closely spaced electrodes. With the larger capacity baths several pairs of electrodes are normally provided, each pair generating salt by virtue of the electrical resistance of the molten salt. In both cases the current is supplied at low voltage from a step-down transformer provided with tappings and an off-load tap changing switch to enable the input to be varied to suit working conditions, *i.e.*, starting up, normal working, and stand-by.

Both processes lend themselves readily to continuous pickle lines, this being particularly so with high-alloy steels where the salt immersion times are no longer than those required for the acid pickling of plain carbon steels.

The mechanical equipment required to handle coils at the entry and exit end of such a line would be similar to the units installed on the conventional continuous acid pickle line.

CONTINUOUS-STRIP PICKLER

GENERAL LAYOUT

The general layout of the modern continuous

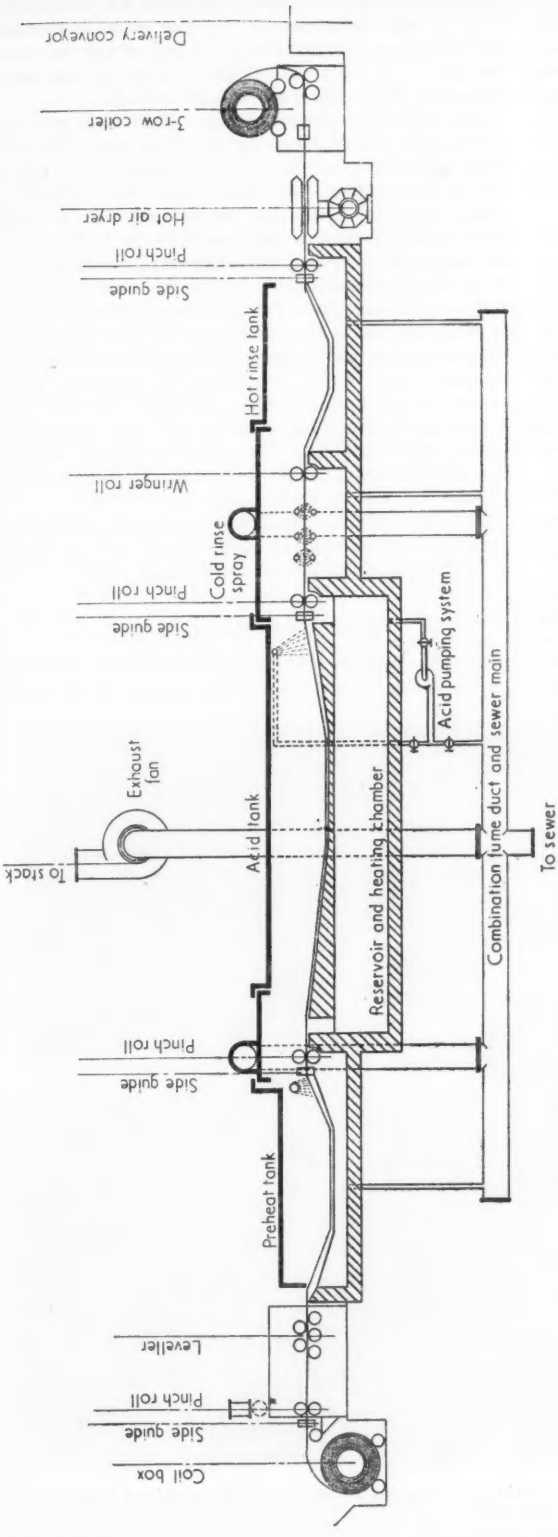


Fig. 1—Arrangement of a semi-continuous type of pickling plant shown schematically

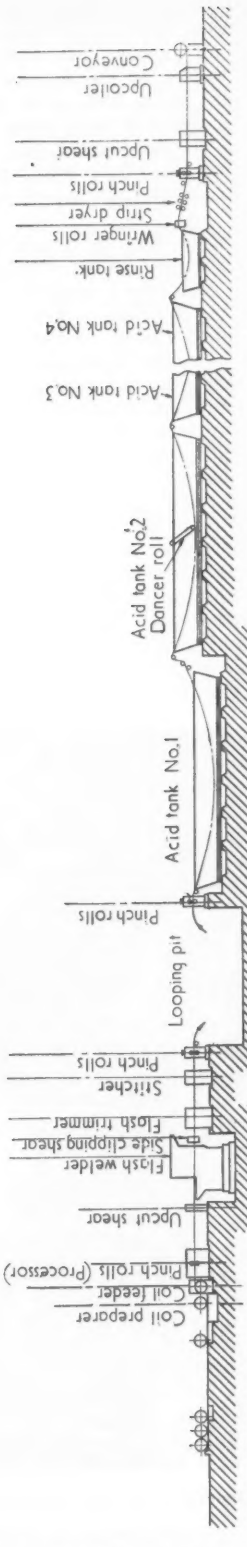


Fig. 2—Arrangement of a typical continuous pickling plant shown schematically

acid strip pickling line, which embodied the mechanical and electrical features developed to date, would consist of an uncoiler, processor, leveller, an upcut shear, a welder or stitcher (or both), pinch rolls, looping pit, pinch rolls, acid tanks with support rolls, water tanks or spray tanks, dryer, pinch rolls, possibly a second looping pit, shear, and recoiler. In some installations a side trimming unit is also incorporated at the exit end of the line preceding the final shear.

In operation, the coil is paid off from a feed reel, this, in most cases, being either a mandrel type or a cone type reel, into a specially rugged processor or scale-breaker leveller. The more modern scale-breaker units consist of two sets of breaker rolls operated by either hydraulic or mechanical means. The breaker rolls are arranged so that the strip is pulled round small-diameter rolls, thus subjecting it to a reverse bending before passing through the roller leveller. This bending action causes a number of very fine closely grouped breaks in the scale, which helps the pickling action by permitting greater penetration for the acid. The levelling operation also flattens the strip and assists in eliminating subsequent breaking in the pickle lines.

The strip passes through a cropping shear, usually of the upcut type, which is arranged to shear the leading and trailing ends of the strip, in order that these can be butted in the following welder. If a stitcher unit is also included in the line it is more common for this machine to be used for joining the ends of long strips merely for the passage through the line, these stitches being cut out at the exit end. The welder in this case is used for producing large coils with welds suitable for cold rolling.

The strip next passes through pinch rolls into the looping pit, which is usually 30–40 ft. long, 10–15 ft. deep, and has a width slightly greater than that of the pickling tanks. On some plants this pit is filled with water to damp the movement of the loops formed in the pit. If hot water is used this serves to preheat the strip and thus reduces the work required of the heating installation in the first acid tank. The looping pit provides storage for a sufficient length of strip to allow the entry end of the line to be stopped for the welding or stitching operation without slowing down the strip passing through the pickle tanks. It is essential that all units of this entry section preceding the looping pit can operate at synchronized speeds. The strip is passed through No. 2 pinch rolls which follow the looping pit, and so into the first pickling tank.

The general arrangement of a typical continuous line is shown schematically in Fig. 2 and illustrated in Figs. 3 and 4, viewed from the entry end.

OPERATIONAL METHODS

At the present time two methods of operating pickle baths are in force. One method is to install

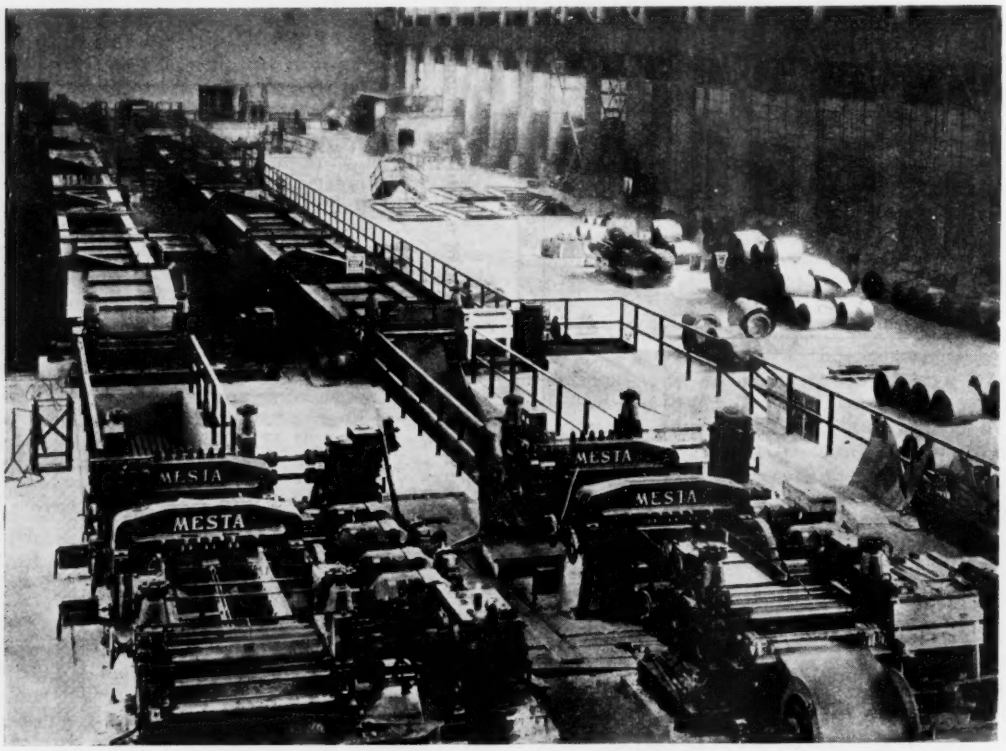


Fig. 3—General view from the entry end of a typical continuous pickling plant, showing combined scale breaker and leveller

the normal four tanks in such a manner that each tank is maintained individually and is dumped whenever it becomes inactive, *i.e.*, at least once in 24 hr. under normal conditions.

In some of the latest installations No. 1 acid tank is placed at a lower elevation than the remaining three, and when any of the last three tanks reach saturation, or their action is too slow, the solution is dumped into No. 1 tank by gravity, this tank acting as a form of rough pickle which removes the major part of the heavy loose scale. This method has recently been modified to a continuous cascade system in which fresh acid is added to No. 4 tank only, and the acid solution is allowed to run from No. 4 tank through the preceding tanks into No. 1 tank and to overflow. This mainly has been instrumental in dispensing with the variation in tank level, the effect being obtained by means of a differential hydraulic head. With the continuous cascade system the acid strength decreases from approximately 23 to 26% by volume in No. 4 tank, to 9 to 11% by volume in No. 1 tank.

The speed of pickling is, of course, determined by the characteristics of the scale and by pickling conditions generally. For the majority of plants in operation a speed of 300 ft./min. has proved to be an efficient maximum. The mechanical speed on modern lines is approximately 400 ft./min. maximum, but with the demand for greater tonnages of cold-reduced steel, and with the tendency for higher capacity cold mills, the need for faster pickling is obvious. It is the tendency for mill designers to develop plants capable of dealing with large coils of a weight of 8000 lb. or greater, and this in turn has necessitated the investigation of pickle and bath capacity. Bearing in mind that the mechanical and electrical equipment is capable of dealing with higher strip speeds for modern pickle lines, the alternatives are more pickle tanks or longer tanks.

Considerable investigation is now being made to determine the exact form a pickle line will take for a required output. Since the pickling rate depends upon the activity of the pickle bath, and also upon the nature of the scale, these factors have received considerable attention. Much has been written on the theory of acid pickling, but investigations in some instances have been carried out with a lack of knowledge regarding the composition and formation of oxide scale on steel exposed to air at high temperature. It has been shown by investigation that when iron or mild steel is heated to a temperature in air, an oxide scale can be formed on the surface of mild steel or iron base material which is composed of layers of oxide, each layer having a decreasing oxygen content from the exposed surface down to the layer immediately in contact with the iron. This formation can be considered as a diffusing process, in which the accession of oxygen from the air diffusing from the outside and a supply of iron diffusion from the iron base metal play an important part. The nature of the layers and their development depend on the time and temperature of exposure in air. In general, the typical iron oxide scale consists of three phases, namely : (*a*) Decomposed ferrous phase adjacent to the steel base, (*b*) magnetite, and (*c*) the outer layer of ferric oxide. It is considered that magnetite and ferrous oxide are relatively insoluble in sulphuric acid baths and extremely difficult to pickle, whereas the ferrous phase is considered to be soluble in acid.

In a scale consisting of magnetite and ferric oxide the ferric oxide is reduced to FeO, this being composed of iron and oxygen, and is thus soluble in the acid. If the iron scale is cooled down rapidly from above 575° C., magnetite separates out with some very fine iron particles, which condition does not permit any electrochemical couple to be split up between the iron particles and the magnetite, and since magnetite is relatively insoluble in the normal pickling acids this oxide would be difficult to pickle. However, if the scale is cooled at a slow rate, in order to separate iron in a finely divided condition of sufficient size to set up electrochemical cells with the magnetite, the magnetite would be reduced to a ferrous-phase condition, which is soluble in the pickling acids, and rapid pickling would take place. On the other hand, if the scale were to cool too slowly the precipitated iron particles would be increased in size, thus reducing their number and, in turn, the electrochemical cells would be reduced and slower pickling would result.

Pickling processes, which in the past were considered to be simply a solution of metal oxides in an acid solution, are now known to be more complex, involving a transfer of electrical charges, the setting up of secondary cells, and the solution of the reactionary products of these cells. The fact that the oxide becomes cathodic and the steel anodic in acid solution is generally regarded to be the case by investigators. The acid penetrating the scale reacts on the " ferrous phase " and the magnetite of this scale is reduced to ferrous oxide, which in turn is dissolved by the acid, thus liberating hydrogen. This action results in the outer scale being loosened and lifted from the surface, which, although slow in dissolving, usually dissolves in the acid after a period of time.

The nature of the steel to be pickled also influences the solution strength. High-carbon steels should have stronger solutions than low-carbon steels, in order to obtain a short sharp pickle, and low-carbon

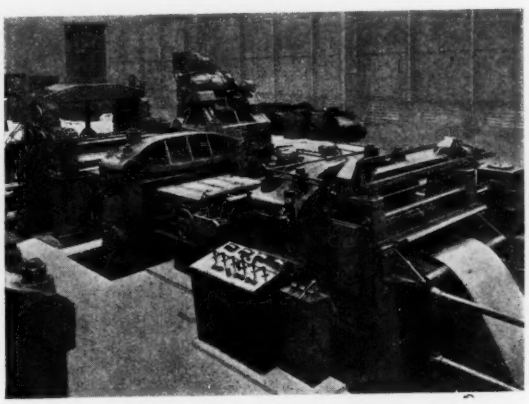


Fig. 4—Steel strip entering a continous pickling plant

open-hearth steels should have stronger solutions than low-carbon Bessemer steels. Some alloy steels also require a strong solution. Again, material if coiled too hot, may carry a spotty scale, resulting in uneven and very slow pickling.

Strong solutions and high temperatures, while increasing the pickling rate, give rise to the danger of over-pickling or pitting of the strip. Since the acid attacks the iron but not its carbon content, over-pickling is accompanied by a visible black coating.

COIL FEEDING AND SPEED CONTROL

Coils are usually delivered to the entry end of the line by driven or gravity conveyors, or by overhead crane.

Two types of coil-feeding machine are in common use on pickle lines, one being the feed reel which is arranged to carry the coil whilst the strip is passing through the line, the other being a combined coil feeder and processor. The mandrel type of unit is not often used.

With the processing uncoiler type of unit the strip is bent in reverse directions by the breaker roll and the entry into the first pinch roll. With the feed-reel type of entry unit it is noted that no processing is actually performed on the machine, the unit being merely to carry the coil. Back tension is created on this unit by either mechanical brake or drag generator, this being instrumental in ensuring sufficient tension in the strip for the scale-breaking operation which is performed in a separate unit. In this case the strip is subjected to a double bend which greatly assists in breaking the tight scale encountered on the edges of the strip.

Speed control throughout the line is accomplished by either magnetic control system or by variable-voltage Ward-Leonard control. The latter method is used almost exclusively on the latest high-speed installations. The speed range for the modern plant is 90–400 ft./min. This, of course, involves a speed on the entry section of approximately 800 ft./min. maximum in order that the coils can be fed into the line and welded while the looping pit reserve is being used for the purpose of maintaining the passage of the strip.

SHEARING AND WELDING

The shear is normally of the conventional upcut type, operating as a self-contained unit with push-button control, a limit switch and brake being included in the equipment to ensure that one cut only is made. If welds are required to pass through the cold mill, it is normal for the shear to make a cut at an angle across the width of the strip, to correspond with the angle of the welding dies in the flash butt welder.

The process of flash welding consists of heating by resistance, burning away the edges by flashing, and then upsetting the metal while hot, thus forming a butt weld. The weld is then trimmed smooth by passage through a plough of **V**-shaped cutters.

The object of the current design of welding machine has been to produce a machine which is completely self-contained. Equipment is included for centring the sheet during operation, and there are devices also for trimming edges and flash upsets and cleaning dies. Full consideration has been given to the requirements of producing welds sufficiently ductile to withstand the strains inherent in cold rolling at high speeds. All operations and adjustments are performed to ensure that varying widths and thicknesses of material are readily handled. Full consideration is also given for rapid changing and replacing of welding dies, a spare set normally being kept available for service, with special grinding equipment for maintenance of the dies.

All controls are normally interlocked so that the full operational sequence can be maintained, and, to quote an example, machines are available which can perform the complete cycle in 90 sec. A current density of 3000 amp./sq. in. is considered advisable for obtaining the requisite weld, the current demand varying with the speed and, therefore, being directly proportional to the arc current. For example, in the case of 40-in. wide strip having a thickness of 16 gauge, the weld-flashing-period demand is approximately 90 kVA., and for 24-in. wide by $\frac{1}{4}$-in. thick material the current demand is approximately 200 kVA. during a similar setting. During the material-upsetting period, when the arc is cut off, the current demand rises to approximately 700 kVA. Figure 5 illustrates a flash butt welder in operation on a continuous pickle line.

Weld Hardness

Several factors which demand consideration when dealing with the question of weld hardness are : (*a*) Die gap after welding (*i.e.*, the amount of material between the dies after welding) ; (*b*) the rate of flashing of the material being welded ; (*c*) the welding current per square inch on the cross-section being welded.

It is possible on modern machines to produce a weld which indicates a Brinell reading of only a few figures above that of the parent metal, and this feature has considerable bearing on the subsequent cold-rolling process. It has been found by experience that weld hardness varies according to the amount of upset obtained, but the time for the upset operation is always kept to a minimum to avoid oxidation of the molten metal. During tensile tests of low-carbon steel it has not been found possible

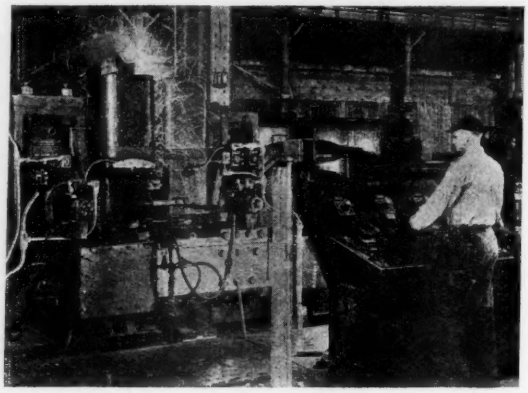


Fig. 5—Flash butt welder in operation

to break the material at the joint of the weld. Fracture usually occurs at a point adjacent to the weld, although the ultimate strength of correctly welded material will be found to come within the same zone as the parent metal.

STITCHER UNIT

Operation of a flash butt welder for merely joining the ends of the strip for passage through the line is an expensive one, and, therefore, a stitcher unit is normally included for this purpose. This machine is exactly similar in design to the upcut shear, except that the shear blades are replaced by punches and dies, whereby the lapped strip is pierced and projecting portions are turned up in the shape of a **W**, these projections being rolled flat in the following pinch roll.

The pinch rolls which follow the stitcher unit are arranged so that the top roll can accommodate the double thickness of strip in addition to the upturned portion of the stitching laps. The entry section of a continuous pickle line terminates, from a control aspect, at this machine, as the strip, on leaving the pinch roll stand, is fed into the looping pit. Specially designed guide rolls are provided to eliminate any kinks which may form in the material.

The strip is removed from the looping pit by a further set of pinch rolls, which feed the material to the acid tanks.

PICKLING TANKS

In considering the design and construction of pickle tanks to meet present-day conditions three main points have to be taken into account :

(i) The exact chemical nature of the pickling solution to be used, together with the temperature conditions which obtain
(ii) Chemical conditions to which the tanks will be subjected
(iii) Constructional strength of the tanks called for by all conditions.

Owing to the relatively high cost of acid-resisting materials necessary to meet the chemical conditions, it is rarely practicable to construct the tanks throughout of such materials. The design must, therefore, provide a tank of sufficient constructional strength, lined with some form of acid-resisting material which, while fulfilling its main function of chemical resistance, will be sufficiently robust to withstand the chemical loads without failure. The ideal acid-resisting lining would, of course, be one which could be applied to the inner faces of a tank in a continuous homogeneous surface which would remain stable under pickling conditions, but few of the materials available at the present time possess the necessary mechanical strength to meet the demand, *e.g.*, bitumen, rubber, and synthetic resins are of this group. It is again very necessary to protect this inner lining with a further lining, which, although not necessarily completely impervious to acid percolation, will retain its mechanical strength while in contact with acid solutions. This is normally done by the use of acid-resisting bricks or tiles set in a suitable cememt.

Brick or reinforced concrete tanks are usually employed in cases where bitumen or acid-resisting-asphalt type of sealing layer is to be included in the construction of the lining. This type of construction is most suitable for straightforward hydrochloric and sulphuric acid liquors where the working temperature does not exceed 55° C. For temperatures above this it is usual to substitute rubber for the asphaltic form of sealing layer, and for most standard pickling solutions a temperature of 100° C. can be worked to without detriment to the lining.

For the rubber type of lining steel outer tanks are preferable, especially if the size is small enough to permit the vulcanizing of the rubber lining by the manufacturers, although modern rubber covering methods do permit the application of satisfactory rubber lining to steel tanks on the actual site, the rubber being applied in sheet form in a semi-vulcanized condition, and the joints being carefully made and electrically tested. By the incorporation of special accelerators in the rubber mix, complete vulcanization is readily effected either by hot-water curing, or in many cases during the first few hours of the tank's active life, when it has been put into commission after the acid-resisting brickwork has been installed. This method can also be applied to concrete or brick tanks.

In the case of the more complex pickling solutions employing nitric or hydrochloric acid for the descaling of stainless and other special steels, the same type of construction can be followed, but special forms of synthetic rubbers, such as butyl or P.V.C. plastic sheets, which are more resistant to the oxidizing acids, take the place of the standard acid-resisting rubber, and special synthetic resin base cements are substituted for the normal acid-resisting cements for the brickwork lining. For the higher concentrations of hydrofluoric acid it is necessary for the standard fireclay type of acid-resisting brick to be replaced by special compounded bricks.

It is, of course, essential that, in the construction of the larger types of tank, working under the higher range of temperatures, due precautions are taken in the design to allow for the difference in expansion coefficients in the respective materials forming the tank structure and lining. For this purpose specially designed rubber expansion joints are normally inserted in the brickwork lining.

It is preferable for the section of the foundations which support the tanks to be faced with acid-resisting tiling, as considerable damage to foundations and shop floors can occur before it is noticed.

On a continuous acid strip pickling line there are usually four pickling tanks, each having inside dimensions of 60–80 ft. length and approximately 4 ft. depth, the width being 8–12 in. wider than the maximum width of the strip to be pickled. The tank construction is steel with rubber and brick lining. The thickness of the brick sheathing varies, and the composition of the rubber lining is constant. The tanks are not normally provided with drains, but are emptied by an arrangement of siphons constructed of lead, or a side discharge runaway arrangement which incorporates an acid level and overflow device, the latter method being the more efficient. Spaced between each tank are rubber-surfaced support rolls. Specially designed hold-down rolls are installed in some plants to ensure the

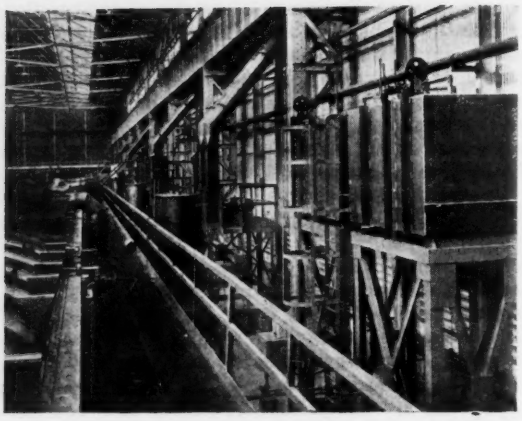


Fig. 6—Acid-tank section of a continuous pickling plant

maximum immersion throughout the length of the tank, but this practice is becoming outdated, and the present tendency is to eliminate these rolls, particularly because of the necessity for the complete unit to be in acid-resistant material, and also because it has been found in practice that these rolls do not have such an appreciable effect on the pickling time.

An illustration of the tank section, typical of a continuous pickling plant, is shown in Fig. 6.

Pickling Solutions

The pickling solutions are heated by steam, either by direct injection or in closed coils. In the injection type of equipment, which is most commonly used, condensed steam makes up for losses by evaporation, drag-out, splash, or spray. In addition, the injected live steam provides agitation which considerably assists in the pickling action. The injectors on one side of the tank are located so as to direct the steam in practically a vertical direction, and those on the opposite side are located with a direction slightly above horizontal position, thus giving a rolling motion to the liquor throughout the length of the tank. Automatic temperature control is normally fitted for the steam supply, controlled by motorized or diaphragm-operated valves.

In recent years immersion flame burners have been developed and tried, but to date they have found application only in small units. They have an extremely limited temperature ceiling, approximately 180° F. maximum, this being well below boiling point and certainly not suitable for pickling plants using acid concentrations up to 20%.

Sulphuric acid (H_2SO_4) is most commonly used for pickling, mainly for the reason of its low cost. The strength of the solution varies in different installations, but normally ranges from 6 to 26% by volume of 100% H_2SO_4. The temperatures of the acid tanks are normally maintained between 190 and 210° F. Experiments have been carried out with acid concentrations up to 30%, thus giving the attendant increase in temperature, but this has indicated a tendency to decrease the pickling rate.

The efficient activity of the acid tanks naturally decreases, owing to the presence of the increasing quantity of dissolved iron sulphate. For this reason fresh acid must be added to maintain the desired bath strength. Should the iron sulphate content reach saturation point it will commence to crystallize in the pickling tanks, and if this occurs the hard crystal deposited is extremely difficult to remove—in some instances it has had to be broken up by mechanical means or by light blasting.

Inhibitors

Many of the difficulties attending the pickling of iron and steel can be avoided by the use of an inhibitor in the bath. Inhibitors are usually of organic origin, and in the pickling bath form positively charged colloids which move to the negatively charged areas and are absorbed at the surface of the steel. Since iron is anodic to scale the inhibitor does not protect the steel surface until the scale has been removed. Inhibitors reduce the evolution of hydrogen, lower acid consumption, decrease pickling loss, control the process, and tend to prevent over-pickling, but they may add as much as 10% to the pickling time.

Activity of the Acid Bath

As pickling progresses the activity of the bath gradually slows down, owing to the presence of dissolved iron sulphate. Dilution of the bath by the steam used to heat it also occurs, but in modern plants this factor is not considered as so important, particularly where the plant is operated on the cascade system, when fresh acid is being continually added to maintain the desired bath strength. A tank is normally used until it is no longer sufficiently active ; this point is usually at a strength of 4 to 9% acid. Iron sulphate commences to crystallize in the bath when the dissolved iron content reaches about 10%, this representing about 50% iron sulphate. It is more usual, however, to dump a tank before reaching this point.

Acid Consumption

Acid consumption per ton of material depends on the gauge of the material and the type of scale. Production figures for acid consumption range between 35 to 70 lb. of acid per ton of strip, the more modern lines averaging a consumption of about 45 lb./ton.

EXHAUST SYSTEMS

Considerable attention should be given to the fume exhaust equipment which must be fitted to the high speed continuous plant. The capacity of the exhaust plant is governed by the temperature conditions to be maintained in the acid and washing tanks, and the effectiveness of the enclosure of the tanks, particularly where the support rolls are not covered by hoods. All inspection openings should, of course, be restricted in area and fitted with rubber screens.

In some cases a separate exhaust fan is supplied in each tank, but on modern lines it is more common practice to install an exhaust unit with trunking running the length of the tanks, this being properly proportioned and provided with branches to the exhaust connection on each tank cover. The main

exhaust unit can then consist of either one fan, or of two fans designed to run together under normal conditions, but each being of sufficient capacity to give a reasonable rate of exhaust should one fan be shut down temporarily for overhaul. The ideal condition, of course, is to have two fans of identical capacity with one unit available as a standby.

The exhaust trunking system is normally built in flanged sections of heavy gauge mild-steel throughout, and is lined internally with hard rubber, giving complete protection of the metal surfaces. The fans are lined similarly, and in a simple form of exhaust plant this equipment alone would suffice to handle the fumes discharged from the tanks, the products being exhausted directly to the atmosphere. On larger plants operating at higher temperatures, however, it is essential that the acid fumes are efficiently scrubbed, and this is normally done by means of water sprays. The use of water for washing purposes has the additional advantage of assisting in the preservation of the rubber lining of the fans and ducting. The fans are normally installed on the outgoing side of the scrubbers so that the maximum quantity of acid is removed from the air before it passes through the fan, and the full benefit is thus obtained from the water-spray system in reducing the temperature of the air handled, and so shielding the rubber lining of the fan. In addition, of course, the increase in the humidity of the air, and the fact that an appreciable amount of water mist may be drawn over by the fan, preserves the rubber, both of the fan itself, and of the exhaust stack into which the discharge is taken.

The design of the scrubbers or washing towers for such plants is receiving considerable attention. The simplest form of equipment consists merely of a series of water sprays introduced into the suction piping in advance of the fan. These may take the form of simple nozzles or perforated piping. The diameter of the trunking might be increased for this section to give some reduction in air velocity, thereby reducing the possibility of carry-over.

Although in some plants this simple equipment has been found to be sufficient, on larger high-speed lines a more effective scrubbing plant is essential. In such instances the fume-laden air is passed through a scrubbing or filtration unit, designed either as a series of towers working in parallel, or as an individual unit, depending on the size of the installation. The air velocity is reduced considerably and is generally on the lines of figures used for normal spray air washing on ventilating and other similar plants. The scrubbers are normally fitted with a number of baffle and deflecting plates to ensure an even flow of air over the entire cross-sectional area, and the water-spray nozzles are specially designed to give a fine spray or mist, through which the air is passed. In addition, a series of water-washed eliminator plates is normally fitted, in order that the air can be passed at a low velocity through an indirect path to impinge on the surface of these plates, thus trapping the greater proportion of the water mist.

The scrubbing towers are normally constructed from steel plate, rubber-lined throughout.

WATER CIRCULATING SYSTEM

The water circulating system is normally of a self-contained type, and comprises a centrifugal pump, with standby equipment, which draws water from a sump into which the scrubbing towers can be drained. It is normal for this sump to be on the pickle line side of the scrubbing towers, so that the fume-laden air is carried to the sump, which is arranged as an expansion chamber from which products can be drawn by the suction of the fans. In this way an additional drop in air velocity is gained, with the

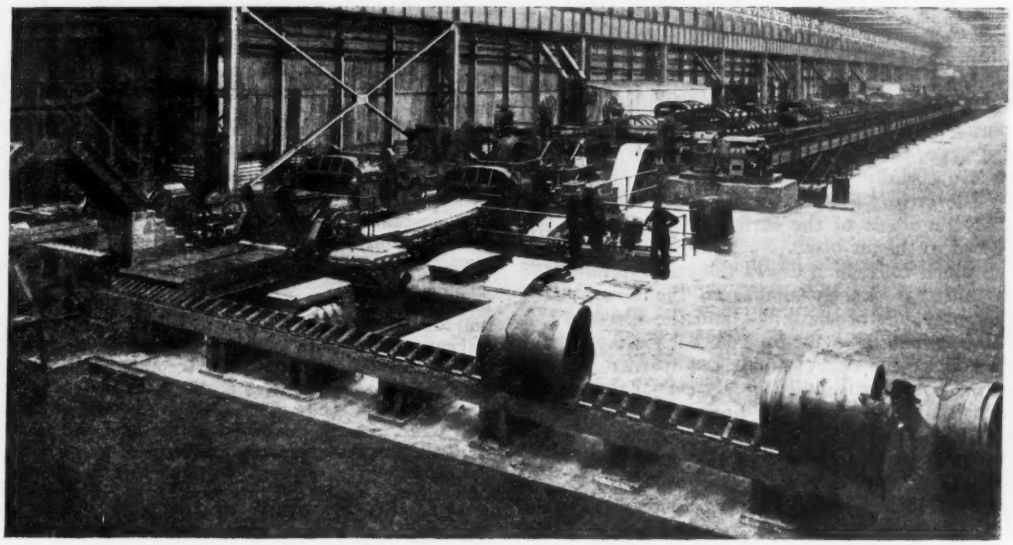


Fig. 7—View at the exit end of a pickle line, showing coil-discharge conveyors

result that a quantity of the acid-laden fumes is settled out.

The design of the fan normally used on this type of plant is of the straightforward paddle-blade impeller type which is easy to cover with rubber, and also enables the impeller shaft to be completely protected.

RINSING, DRYING, AND RECOILING THE STRIP

The strip, on leaving the acid tank section, is passed to the washing tanks, where it first receives a cold-water rinse and then a hot-water rinse. Usually, two separate tanks are used, the construction of which is exactly similar to that of the acid tanks themselves, in that they are of steel, and are rubber lined, with acid-resistant brick facing. On some plants, however, a development of this section of the line has led to the use of what is known as a spray-rinse tank, this consisting of a single tank divided into two sections internally, and complete, as before, with rubber and brick internal facing. Hold-down and support rolls, also rubber faced, are incorporated in the tank structure, and pressure water sprays have been introduced, with the idea of virtually scrubbing the surface of the strip to remove the adhesive fine scale dust which was found to be left on the strip on leaving the acid. Early designs of this form of rinse tank incorporated the use of rotary bronze-wire brushes, but more efficient scrubbing has been obtained by the omission of these brushes and the increase of the water pressure.

Four pairs of cold-water sprays are usually fitted, followed by eight pairs of hot-water sprays, water being delivered to these sprays at a pressure of 100 lb./sq. in. Special jets are used to give a flat fan-shaped jet, spaced so that the entire surface of the strip is exposed to the water spray.

A hood is included with this unit, having an exhaust connection which carries fumes to the exhaust system previously described. A set of rubber-covered wringer or squeegee rolls removes the major part of the surplus water on the material, following which a high-pressure hot-air blower dries the strip before it is recoiled.

The drying unit itself comprises a multi-stage fan delivering air through a heater, normally of the steam-heated type, to special **V**-shaped headers, of which there are usually three pairs located above and below the strip. Slots are arranged in the headers so that the whole of the surface of the material is subjected to the air blast.

The pinch roll which draws the strip through the rinse tanks, is exactly similar to the unit located at the entry side of the tanks, and the speed of this machine, which is synchronized with that of the pinch roll at the entry stand, is governed by the dancer-roll mechanism. Normally the side trimming unit is located next in the line, and this unit is followed by a second upcut shear to remove the stitch or weld, special provision usually being made for scrap removal.

On some lines a looping pit is provided as part of the exit-end machinery, so that the shearing and final coil forming can be performed without the necessity of stopping the line. In practice, however, it has been proved that the period of dwell is so short that there is no effect on the material while in the acid, and the line is usually stopped. A typical view at the exit end of a pickle line is given in Fig. 7.

On the greater number of modern lines the coils are remade by a 3-roll upcoiler. Included in this unit are entry pinch rolls and the necessary cradle rolls for supporting the coil while it is being built up ; an oil attachment also is normally provided, so that the material is prepared for the cold rolling operation and proofed against atmospheric conditions.

A problem which has entailed considerable investigation is that of guiding the coils while in the uncoiler. Excessive wear is encountered on the side guides, owing to the abrasion and tearing action of the edge of the strip when in contact with the guide rollers. Although various forms of side guides have been tried, the difficulty remains. Such wear is, of course, eliminated to a great extent by the inclusion of a side trimming unit in the line, but a number of operators prefer to deal with the trimming operation as a separate process.

Acknowledgments

The author gratefully acknowledges the help of Messrs. Prodorite Ltd., British Federal Welder and Machine Co., Ltd., and Sturtevant Engineering Co., Ltd., who assisted in assembling relative specialized information.

Films about Metal

A new film catalogue, " Films about Metals," prepared in conjunction with the Joint Committee on Metallurgical Education, has been published for the Scientific Film Association. It is the first of a series on specialized subjects which will ultimately replace the " Catalogue of Films of General Scientific Interest." Titles of about 200 films are given, together with running time, gauge, and distributor and, wherever possible, a brief synopsis of content is given.

Copies of the catalogue may be obtained, price 3*s.* 6*d.* (3*s.* 8*d.* post free, 2*s.* 8*d.* post free to S.F.A. members) from Current Affairs, Ltd., 19, Charing Cross Road, W.C.2.

Industrial Films

Imperial Chemical Industries are prepared to loan, free of charge, to trade and technical associations, a number of technical, educational, and general interest films. A film called " Rock of Industry " opens with blasting operations at Thustead, in Derbyshire, and goes on to show the essential rôle of limestone in the manufacture of iron and steel, bleaching powder, and in the building and textile industries, public utility services, railways, engineering and tannery trades, and in agriculture. A film entitled, " A Ship comes in from Texas," depicts the general chemicals division of Imperial Chemical Industries, Ltd., and includes hydrochloric acid, used in large quantities in the iron and steel and textile industries ; trichlorethylene, used as a solvent for metal degreasing, in dry cleaning, and in oil and fat extraction ; sodium cyanide used for gold refining, case-hardening chemicals, and for insecticides and weed-killers. The films are made for 16-mm. sound projectors. Further information can be obtained from the I.C.I. Film Library, Bolton House, Curzon Street, London, W.1.

The Disposal of Spent Acid Pickling Liquor

By W. B. Wragge

SYNOPSIS

A survey has been made of methods, generally employed throughout the world, for dealing with spent pickling acid, emphasis being laid on sulphuric acid liquors. The neutralizing and crystallizing techniques associated with acid recovery are discussed. Information has been obtained on operating costs and materials of construction for some of these processes. Continuous and batch treatment processes are discussed, and comparison is made between freezing and water-cooling as applied to crystallization methods. The advantages and some of the disadvantages of the foregoing are surveyed. To facilitate the calculation of theoretical and practical operating cycles in acid-recovery treatment, a useful ternary equilibrium diagram, $H_2O/FeSO_4/H_2SO_4$, is included in the paper. The problem of the disposal of ferrous sulphate, the by-product of acid-recovery processes, is considered.

The volume of spent acid liquor now produced by the steel industry is stated to be assuming major proportions, and the concluding remarks contain a few suggestions designed to reduce the dimensions of the problem, and which in addition would lead to the more effective use of pickling liquors.

Acidic liquors, particularly hydrochloric acid and sulphuric acid, have for many years been favoured, on account of their economic advantages, for the removal of oxide scale from steel surfaces.

The pickling acid attacks both the scale and the descaled steel surface at rates depending on the bath composition, temperature, and type of scale, the by-product of this chemical reaction being sulphate of iron in the case of sulphuric acid, and chloride of iron in the case of hydrochloric acid. The content of the compounds present in solution in the pickling bath increases progressively with the life of the bath. Under conventional operating conditions, pickle-bath activity is reduced at the higher levels of iron sulphate concentration. Economic and technical limitations define the iron concentration of a pickle bath when it is considered to be spent and of no further use. Spent pickle liquors contain, in addition to a high iron content, greater or lesser amounts of free acid, depending on the pickling technique employed.

In the early days of pickling, the volume of spent liquor for disposal was relatively small and was usually run to waste surface water, soak-aways, etc. With increasing steel production the volume available for disposal has increased enormously, and during the last thirty years a great deal of attention has been paid to this subject.[1] As a rough indication of the present-day volume to be dealt with, the sulphuric acid consumed in Great Britain for descaling purposes would produce annually more than 200,000 tons of copperas by-product ($FeSO_4.7H_2O$), assuming no wastage of acid liquor during the pickling process. If the pickle liquor were rendered innocuous for dumping by precipitating the iron from solution by treatment with lime, then the separated wet sludge would weigh over 300,000 tons.

The disposal of pickle acid waste involves not only the spent pickle bath, but effective means must be found for dealing with acidic and ferruginous liquor carried out of the bath by drag-out, spray, and steam dilution in certain cases; and because such waste is often diluted with considerable volumes of rinse water, the handling of such liquor frequently presents considerable difficulties.

Many chemical methods of disposal have been suggested, a number have been tried out, and others have been practised over a period of years, for rendering the liquor innocuous for dumping purposes, or for removing the contaminant iron and recovering free acid which is returned to the pickling bath.

Throughout this paper the following terms are employed with regard to concentrations and compositions:

(1) Composition in weight per volume: % w/v: *e.g.*, 1 lb./gal. = 10% w/v or 10 g./100 c.c.
(2) Composition in weight per weight: % w/w (% w/w × specific gravity = % w/v).
(3) The term 'sulphuric acid' is used for 100% H_2SO_4 w/w.
(4) BOV denotes brown oil of vitriol (77% H_2SO_4 w/w approx.)
(5) $FeSO_4$ = ferrous sulphate
$FeSO_4.1H_2O$ = monohydrate
$FeSO_4.7H_2O$ = copperas.

SPENT LIQUOR COMPOSITIONS

Some typical compositions of spent liquors after use in various processes are as follows:

Pickling bars (batch): 2–10% w/v H_2SO_4, 22–40% w/v $FeSO_4$, at 50–80° C.
Pickling sheet (batch): 14% w/v H_2SO_4, 1% w/v HCl, 40% w/v $FeSO_4$, at 50–55° C.
Large continuous-strip mills: 2–18% w/v H_2SO_4, 18–35% w/v $FeSO_4$, at 190–210° F.
Pickling wire: 0·5–0·7% w/v HCl, 31–32% w/v $FeCl_2$, cold.

Although the foregoing compositions may be considered typical, it should be pointed out that by no means all the sulphuric acid and hydrochloric acid consumed by the steel industry appears ultimately as spent liquor in the composition ranges defined. Acid lost by drag-out and tank overflow (in the case of direct steam injection heating) can assume considerable proportions. A figure as high as 40% has been stated by Sierp.[2] This waste acid requires treatment for disposal purposes. The compositions indicate the free acid which might under certain circumstances be

Manuscript received 18th March, 1949.
Mr. Wragge is a Director and Chief Metallurgist of Exors. of James Mills, Ltd., Bredbury Steel Works, Woodley, near Stockport.

recovered and put to further useful purposes, rather than disposed of. If there were no drag-out losses, the iron increase in a pickle bath would be chemically proportional to the acid consumed. Thus, with a spent liquor containing 40% $FeSO_4$ w/v, the ferrous sulphate is equivalent to 26% H_2SO_4 w/v used up in pickling. If the spent liquor contains, say, 10% w/v of free sulphuric acid, then if this latter acid can be recovered, the possible saving in acid will be in the ratio of $10/(26 + 10) = 28\%$ of total acid used.

METHODS OF DISPOSAL OF SPENT LIQUOR

Among the more common methods of disposing of spent acid pickling liquor are the following :

(1) Direct dumping or sale to the chemical industry.

(2) Neutralizing and precipitating, with or without conversion of sludge (ferron).

(3) Crystallizing surplus iron with free-acid recovery by straight cooling, cooling by vacuum evaporation, evaporation at high temperature, or reducing the solubility by adding chemicals.

It is the purpose of this paper to examine those of the foregoing methods which are of major interest and particularly those for sulphuric acid waste liquors which are most frequently used in steelworks practice.

DUMPING

Direct discharge of spent liquors into rivers and lakes is allowed in one European country, but the discharge must be controlled so that not more than 50% of the natural alkalinity of the water is discharged. Presumably the rivers in the country concerned are large and flow swiftly and the total amount of discharged liquor is relatively small.

Where convenient, discharge to the sea has been suggested, but unless the locality is carefully chosen, damage may be caused to fisheries or beaches.

NEUTRALIZING AND PRECIPITATION

As it is the free acid and the ferrous sulphate of spent liquor that renders it unacceptable to normal river waters, and to concrete and metal drainage pipes and sewage plants, much attention has been focused on methods of neutralizing the free acid with various alkaline materials and precipitating the iron from solution. Hoak[3] has shown that milk of lime is the most efficient neutralizing and precipitating agent, the reaction being accelerated by aeration and heat. Pulverized limestone has been proved to be almost equally efficient. The following relative figures compare the performance of these two agents with that of a caustic soda solution :

	Milk of Lime		Milk of Limestone		Caustic Soda Solution	
Reaction time, min.	5*	5†	15*	180†	Instantaneous*	†
Cost per unit basicity	10·1		6·13		84·4	
Sludge - settling property	0·01		0·13		0·00	
Sludge volume	81		77		96	

* 60° C. and aeration
† 60° C. and no aeration

The resultant sludge, if small in volume, might be accepted by sewage plants, but above certain limits it will interfere with sedimentation tanks and will clog diffuser plates in the activation process and the circulating filters.

Gehm[4] has proposed neutralizing with limestone, employing a technique which prevents calcium sulphate and other sludges from clogging the pores of the limestone. The liquor, having less than ½% of free sulphuric acid, should pass upwards through a 1–2½-mm. limestone bed at the rate of 20–80 gal./min./sq. ft. of bed area, which should be 2–4 ft. deep.

The cost of neutralizing and precipitating 10,000 gal. of spent liquor (5% H_2SO_4 w/v, 30% $FeSO_4$ w/v) with hydrated lime has been examined. A weight of 8·18 tons of lime was required, and a minimum weight of 23 tons of solids associated with some 58 tons of water, as a sludge for disposal. This is equivalent to a total sludge volume of 15,800 gal. (approx.). The operating cost based on a plant providing paddle agitation and employing three men was £70 per week. In this case the quantity of sludge was too great to be accepted by the local sewage, and no tipping site was available. The cost of the operations would add at least 1*s.* 4*d.* to the pickling cost per ton of steel bar of 1 in. dia. (average), with the problem of disposal of sludge still unsolved.

The neutralizing and precipitation technique is frequently utilized for the treatment of acidic wash waters. Snow[1] has described the handling of 50,000 gal./day of dilute acidic liquor, requiring 11 lb. of hydrated lime per 1000 gal. for treatment in a paddle agitator. The liquor was directed to a large settling pond, and the resulting clear, innocuous, supernatant liquid passed over a weir into natural water, the settled sludge subsequently being lagooned. A large area of land was required for this process and the operating cost was $4000 per year.

The sludge by-product of precipitation operations has normally very little value and can usually be disposed of only by the methods described. The Sharon Steel Corporation, however, has undertaken the conversion of such sludge to a useful commodity known as 'Ferron' board. The process has been described by Rentschler.[5]

No large-scale neutralization and precipitation is carried out in this country, although this treatment is applied on a small scale where the local sewage works accepts the diluted sludge effluent.

The U.S.A. has more experience of this treatment, and information supplied by Hoak[6] indicates that the total cost of neutralizing and precipitating volumes of spent pickle liquor with ultimate lagooning of the sludge was of the order of 1 cent/gal. before the war. Assuming a liquor of 30% $FeSO_4$ w/v content, this is equivalent to about 7*d.* per ton of strip steel (before the war)—a low figure for present-day conditions.

Precipitants other than lime have been used, *e.g.*, dolomite, limestone, dolomites, various forms of magnesia, ammonia, etc.

CRYSTALLIZING

The crystallizing methods used for the disposal of spent liquor include all the usual methods of reducing the solubility of the dissolved salt of the contaminant

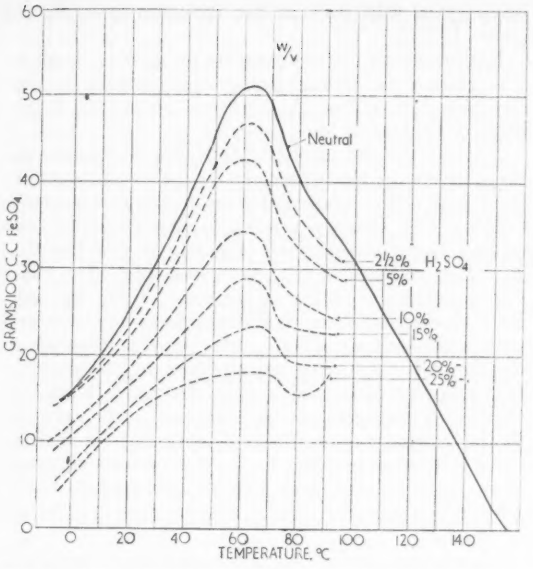


Fig. 1—Solubility of $FeSO_4$ in sulphuric acid and water

iron in the pickle liquor, either partly or completely, and also with or without recovery of the free acid. These processes depend entirely upon the solubility of copperas or ferrous sulphate at varying degrees of acidity and at varying temperatures. As shown by Swindin,[7] the solubility of ferrous chloride in hydrochloric-acid/water mixtures is extremely high, and has only a small temperature gradient. On the other hand, the solubility of ferrous sulphate in sulphuric-acid/water mixtures varies widely with temperature and acid concentration, being at a maximum at 60° C. (approx.) and reducing with increased acidity (*see* Fig. 1).

Solubility of Ferrous Sulphate

An equilibrium diagram of the system $FeSO_4/H_2SO_4/H_2O$ (Fig. 2), due to Swindin,[7] is invaluable for quantitatively estimating the effect of temperature or acid concentration on the solubility of iron sulphate. Spent liquors as defined earlier are usually unsaturated, although high in ferrous sulphate, and it is obvious that the contaminant iron sulphate may in part be removed, either (*a*) by straight cooling, (*b*) by removal of water, or (*c*) by addition of acid in sufficient quantity, or by combinations of (*a*), (*b*), and (*c*).

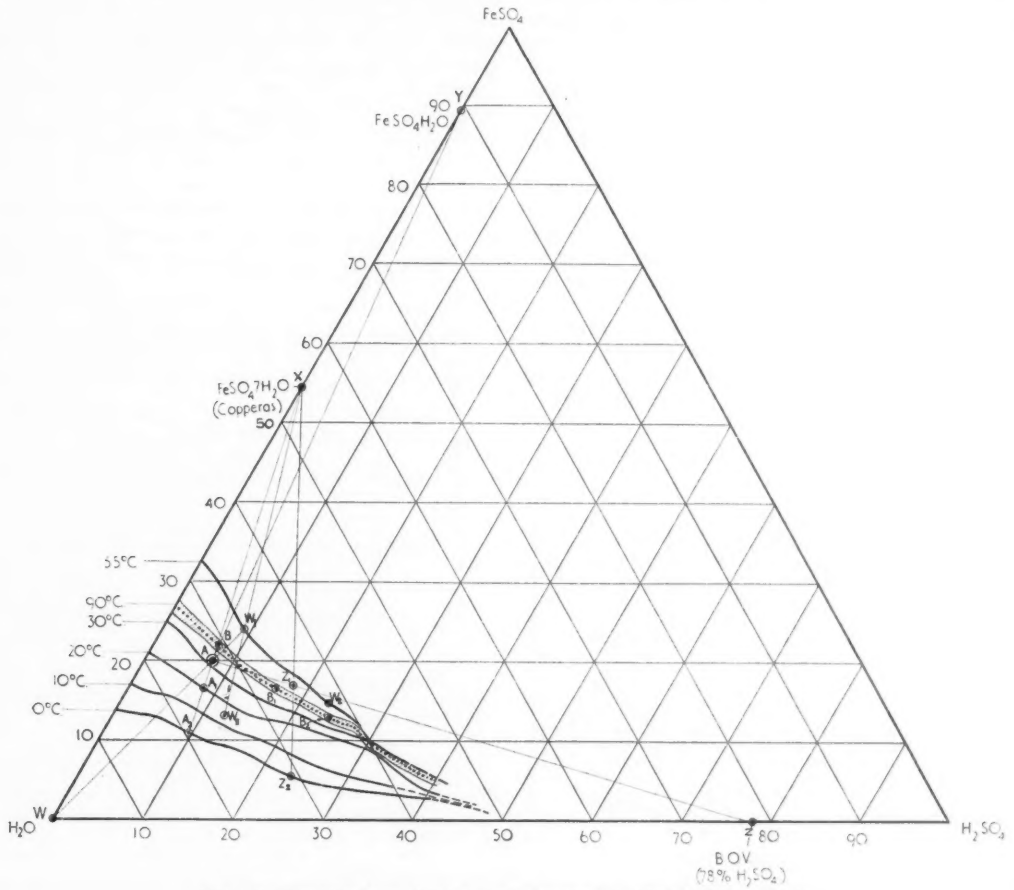


Fig. 2—Equilibrium diagram of the system $FeSO_4/H_2SO_4/H_2O$

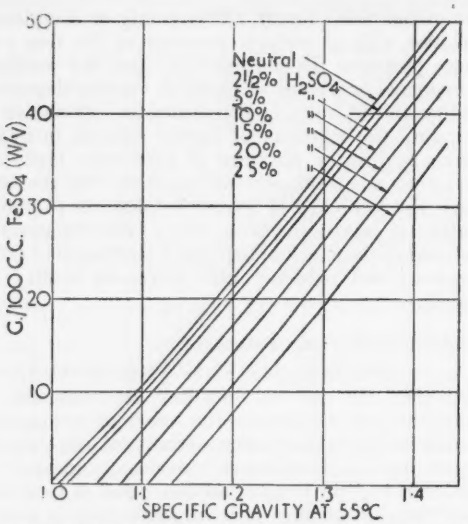


Fig. 3—Specific gravity of w/v sulphuric acid pickle liquors containing dissolved $FeSO_4$, at 55° C.

If removed at temperatures substantially below 60° C., the iron sulphate is in the form of copperas, but the monohydrate is obtained appreciably above that temperature.

By applying the lever principle to Fig. 2, it is possible to ascertain the proportion of iron salt separated out by various methods. Specific-gravity values are necessary for such calculations and are given in Figs. 3 and 4.

Straight cooling of a spent liquor of composition A (Fig. 2), at a temperature of 35° C. or above, is depicted on the ternary diagram (Fig. 2) by line $A \rightarrow A_1 \rightarrow A_2$, which gives the change in the composition of the mother liquor left after crystallization of the copperas.

Removal of water by isothermal evaporation at, say, 55° C. results in a change in composition of liquor A in the direction $A \rightarrow W_1 \rightarrow W_2$. Under vacuum evaporation, however, the temperature of the system will be reduced, and the mother-liquor composition will vary in the direction $A \rightarrow W_3$ (at about 15° C.).

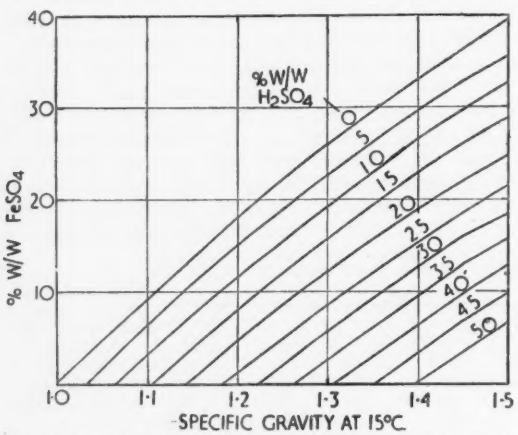
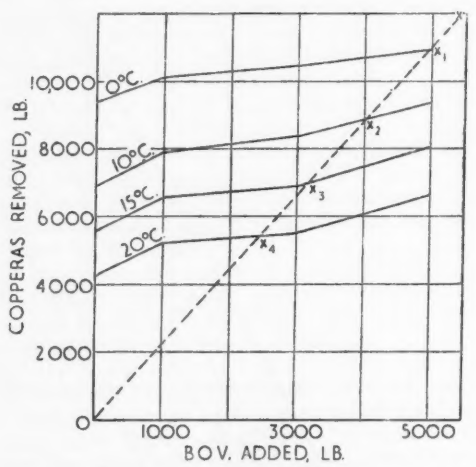


Fig. 4—Specific gravity of w/w sulphuric acid pickle liquors containing dissolved $FeSO_4$, at 15° C.

High-temperature evaporation, or boiling, leads to a variation in mother-liquor composition in the direction $A \rightarrow B \rightarrow B_1$, ferrous sulphate monohydrate separating out.

Addition of acid (as BOV) to liquor A changes the composition in the direction $A \rightarrow Z_1 \rightarrow Z$. At Z_1 the liquor will be undersaturated for its temperature. Cooling will cause copperas to separate out, the mother-liquor composition changing in the direction $X \rightarrow Z_1$ to, say, Z_2, at 0° C. at equilibrium. The lower iron composition of Z_2, as compared with A_2, indicates the increased removal of copperas due to dosing with acid before cooling. The limiting amount of dosing acid which may be employed will be equal to the quantity consumed during the pickle bath life. With such maximum dosing, however, only a portion of the mother liquor would be required for making up a recovered pickling bath ; the remainder would have to be stored and utilized for periodic bath additions compatible with evaporation during the life of the bath.

An approximation of the maximum amount of dosing which could be tolerated can be obtained from Fig. 5. In the case of a completely closed cycle of operations, the maximum amount of BOV to be added will be chemically equivalent to the total amount of copperas removed per cooling cycle. The points X_1, X_2, X_3, and X_4 define the maximum amounts of BOV additions for cooling temperatures of 0°, 10°, 15°, and 20° C. respectively. Additions of BOV in excess of these amounts will lead to a surplus



Composition of liquor (sp. gr. 1·285) : 25% $FeSO_4$ w/v (= 20% w/w), 9½% H_2SO_4 w/v (= 7½% w/w). Initial temp. 53° C., volume 3500 gal.

Removal of Iron as Copperas (lb.)

BOV Dosing, lb.	Cooled to— 20°C.	10°C.	0° C.
Nil	4240	6900	9400
1000	5260	7970	10,120
3000	5480	8390	10,500
5000	6720	9200	10,930

Fig. 5—Effect of dosing with BOV before cooling spent liquor

of acid in the system. In actual practice these values can be exceeded by the extent to which acid is lost by drag out, and for other reasons. For the particular spent pickle liquor composition under consideration, the employment of maximum BOV dosing, in conjunction with cooling to 0° C., leads to an increase in iron removal of 17% by weight. This is equivalent to a prolongation of recovered pickle bath life of 16%. If water cooling only is employed and finishing at 15° C., then the corresponding gain in recovered bath life through maximum acid dosing is of the order of 25%. Cooling to 0° C., however, gives a gain in bath life of 57% when compared with water cooling at 15° C.

In theory, crystallization methods of reclaiming spent sulphuric acid pickle liquor should provide a closed cycle, as far as free sulphuric acid is concerned, none being wasted. The by-product of the operation will be either copperas or ferrous sulphate monohydrate.

In practice, acid is carried out of the system together with some dissolved iron) because of spray, drag-out loss, moist crystals, and sundry spillage. With closed-cycle recovery processes, certain bath contaminants, other than iron, are likely to increase, *viz.*, manganese as manganese sulphate, phosphorus as phosphoric acid, silicic acid, and perhaps the decomposition products of the restrainer additions. Although it has been stated that baths (with periodic recovery) have been in operation without trouble for as long as two years, some operators consider it desirable to scrap the bath at intervals.

Acid-reclaiming systems on these lines have been widely used, working on the intermittent batch recovery or alternatively on the continuous basis, in conjunction with batch-type or in-line continuous pickling plant.

Continuous acid-recovery systems, in which the rate of copperas removal by cooling methods balances the rate of iron increment in the pickle bath, presuppose the use of a substantially constant-composition pickle liquor, and for economic running, a fairly high iron concentration. Where very high rates of pickling are of prime necessity, circumstances may be such that high iron contents of the bath may not be tolerated. Batch methods of recovery are to be preferred where the rate of increase in iron content of pickling baths fluctuates greatly due to varying loads on the bath, and have the advantage over continuous recovery systems in that bath life commences with relatively low iron content with its attendant claimed advantages for certain types of pickling operations.

Straight Cooling Methods

Straight cooling by single stage (to about 15° C., using cold water) or by double stage (*i.e.*, down to 15–20° C. and with subsequent refrigeration to 0° C. or less), has found considerable favour, and some interesting information is available on the performance of such plants which have been designed for batch and for continuous liquor treatment.

In Britain, spent pickle acid recovery systems are batch treatment processes. The general layout of a typical refrigeration plant is indicated in Fig. 6. Hot spent liquor is transferred to a settling tank where sediment separates, whence the clarified liquor is transferred to a water-cooling vessel which brings the temperature down to about 20° C. Further cooling by refrigeration is applied after transferring the liquor from No. 1 to No. 2 crystallizer. The mixture of copperas crystals and mother liquor in No. 2 crystallizer is shot into the centrifuge for separation.

Where the composition of the spent liquor is sufficiently high in iron, refrigeration is frequently eliminated if adequate crystallization has resulted from water-cooling.

As liquors strong in iron easily assume a metastable or supersaturated condition on cooling, agitating stirrers are invariably provided to overcome this condition. It is interesting to observe that the size of the crystals produced can be varied within a very wide range. Thus shock cooling plus considerable

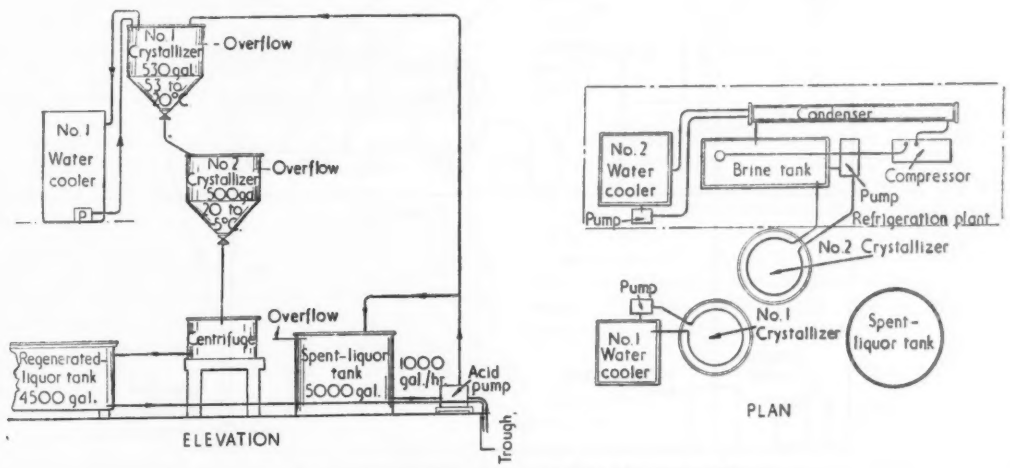


Fig. 6—Diagrammatic layout of acid-recovery plant

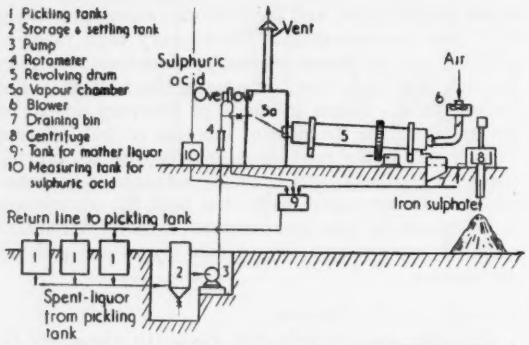


Fig. 7—Diagrammatic layout of Zahn ' Rollkristaller ' (reproduced, with permission, from F.I.A.T. 1117)

agitation can yield crystals so fine that they are difficult to deal with when separating. This problem is fully appreciated by the chemical industry. Dosing with BOV is appropriately carried out prior to the cooling operation.

Evaporation Methods

A simple arrangement at Tinsley Wire Mills, described by Swindin,[7] provides rotating fan blades which feather the surface of the liquid in a spent liquor tank, accelerating evaporative cooling, while crystal seeding is assisted.

A process developed by Arthur D. Little, of the American Rolling Mill Company, involved spraying pickle liquor into the top of an open tank and providing a forced air draft to vaporize some of the water. The author is informed that the process did not prove to be satisfactory on a commercial scale. Nevertheless, it would appear feasible to spray liquor down a high tower to obtain sufficient evaporation and cooling, which would yield adequate copperas removal and acid recovery by the usual means. The construction of such a tower may involve considerable problems.

There is reference in the literature to spray drying of liquor both with and without prior neutralization. Continuous processing of spent pickle liquor would appear possible with such schemes.

The Zahn ' Rollkristaller ' overcomes the tower problem by employing a rotating inclined drum. As reported in F.I.A.T. 1117,[8] liquor passes down the inside of a drum in a thin stream (Fig. 7). The inside of the drum is provided with scoop-like projections and serves to expose a considerable surface area of the liquor to an air current forced through the drum. The mixture of cooled mother liquor and crystals is separated in a draining bin, the crystals being finally centrifuged. The process operates on a continuous basis, and apparently the equipment has been developed fully, since quite a number of units have been used in Germany with alleged success. The relations between diameter and length of drum, liquor temperature, and air flow, have been established. Thus, to handle 66 gal./hr. of pickling liquor at 50–60° C., a revolving drum about 13 ft. in length and 1 ft. 9 in. dia., requires an air flow of 70,000 cu. ft./hr. Larger sizes are built to handle up to 500 gal./hr., with a cylinder length of 35 ft. and a diameter of 2 ft. 9 in. ; power requirement for the air blower is four times that for the plant size first mentioned. Steel

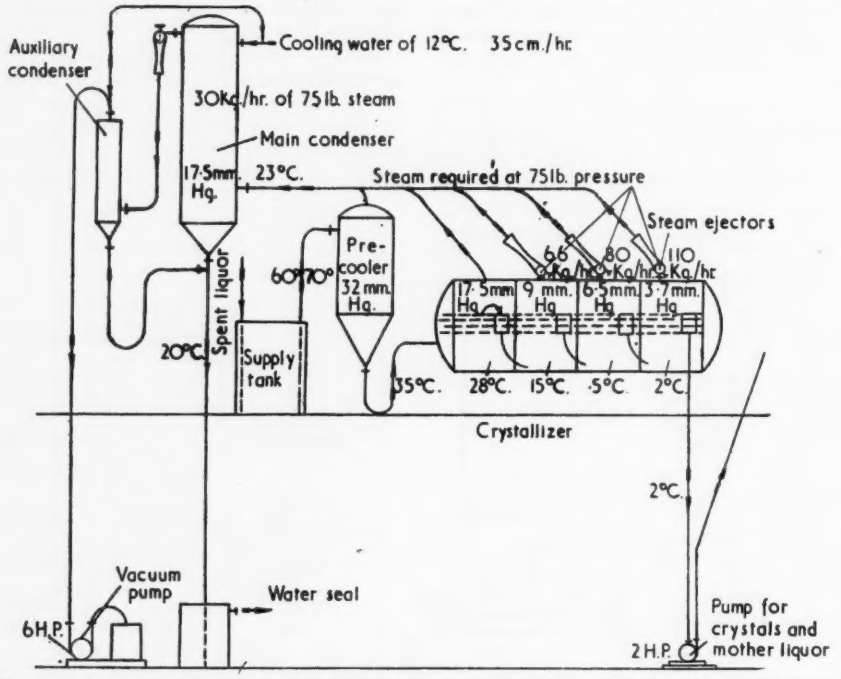


Fig. 8—Diagrammatic layout of Lurgi acid-recovery plant (reproduced, with permission, from F.I.A.T. 1117)

drums are lead-lined and revolve at about 18–20 r.p.m.

Based on estimates of maintenance and overheads taken from British plant figures and ruling prices for labour and electricity, operating costs, excluding plant charges, are at 1*s.* 3*d.* per ton of steel pickled. The use of such a plant on a continuous basis more or less presupposes a constant iron content in the pickling bath of about 25% $FeSO_4$ w/v. Unless carefully watched, the shut-down periods with such a plant are likely to lead to crystallization troubles in the pickling troughs, feed lines, etc.

Vacuum Evaporation

Although well established in the chemical industry for the crystallization of salt solutions, vacuum evaporation appears to be the only method used in the U.S.A. by which copperas is extracted from spent pickle liquor. Acid recovery is not practised, the liquor being neutralized before evaporation. Multiple-effect evaporators are favoured, and from information received, the cost of producing copperas by this manner varied from $6 to $8 per ton before the war.

The advantages of vacuum evaporation are threefold : (1) Heat transfer occurs under most favourable conditions—problems with regard to K* do not exist ; (2) both water loss and temperature drop have a combined effect on quantitative crystallization ; and (3) heat recuperation can be applied with advantage.

A Lurgi evaporator plant of this type, in operation in France, is shown schematically in Fig. 8. The first stage of evaporative cooling results from the use of a vacuum pump and barometric condenser, by means of which a temperature of the order of 25° C. can be reached. Appropriate steam-jet compressors progressively reduce the pressure and temperature in multiple stages.

Operating data for this plant are as follows :

Volume of spent liquor evaporated (4 stages) at 500 gal./hr., composition 31·6% $FeSO_4$ w/v, about 8% H_2SO_4 w/v.

Initial temperature	55° C.
Final temperature	2° C.
Copperas produced	1900 lb./hr.
Cooling-water requirements for condenser	488 gal./hr.
Steam consumption	620 lb./hr.

Steam costs are thus from 1*s.* 4*d.* to 2*s.* 2*d.* per ton of strip. As vacuum evaporation salts out crystals mainly as the result of cooling, and refrigeration performs the same function, it is interesting to compare steam costs of the former with the electrical and ammonia costs of a refrigeration system.

High-Temperature Evaporation

Heat transfer to saturated solutions for the purpose of evaporating water is a serious problem. Heating surfaces are rendered inefficient (*i.e.*, there is a serious drop in K) by incrustation of salt. Ferrous sulphate solutions are especially difficult, the trouble increasing with increasing temperature of heating surface. Attention, therefore, has been paid to the use of hot gases in direct contact with liquor by spray treatments, submerged combustion, etc.

Martin[9] suggests the spraying of spent liquor (from continuous-strip plant, 18% H_2SO_4 w/v, 18% $FeSO_4$ w/v, 200° F. approx.), dosed with recovered strongly acidic liquor, into hot combustion gases from a Petro-Chem furnace, operating on coke-oven gas. The concentrated liquor centrifugally separated from gases now at 215° F., is passed to a crystallizer, dosed with maximum acid, and heated by direct contact with superheated steam from the Petro-Chem furnace. The mother liquor decanted off gives 32% H_2SO_4 w/v, and the ferrous sulphate monohydrate sludge is centrifuged. A completely closed cycle is claimed, as acidic wash water from the pickling line is utilized to scrub waste-gas effluent and to make up mother liquor to a recovered pickle bath concentration of 23% H_2SO_4 w/v, 5·7% $FeSO_4$ w/v. The very low iron content is considered desirable for high-speed strip pickling. Submerged combustion burners offer a different approach to the problem.

Swindin[7] has suggested a submerged combustion scheme ; the advantages of this would be a simple plant, corrosion would be mainly confined to the burner, which may be adequately protected with enamel, evaporation to 40% or more H_2SO_4 w/v would be possible, with ferrous sulphate monohydrate in hard granular form thrown out to the extent of 90% or more of the $FeSO_4$ originally present.

Trials in this country have shown 90% heat efficiency at the boiling vessel and burner. Waste heat in gaseous effluent can be recuperated to the extent of 70% by use of a tubular liquor pre-evaporator. The Nordac system (Fig. 9) shows such a scheme, whereby incoming liquor is sprayed on recuperator pipes through which waste gases circulate, the chamber being subject to air draught. Liquor pre-evaporation occurs, and heat-transmission efficiency is high because saturated gases wet the inner tube surfaces and greatly improve K. A high draught has been found neither necessary nor desirable.

Based on makers' figures of 90% efficiency for the burner and vessel, and a 70% waste-heat recuperation, the following figures have been derived, using producer gas at 6*d.*/therm.

	Batch Pickling	Continuous-Strip Pickling
Composition ...	8·1% H_2SO_4, 18% $FeSO_4$ w/w	14% H_2SO_4, 12% $FeSO_4$ w/w
Fuel cost (per pound of $FeSO_4$ extracted) ...	0·40*d.*	0·35*d.*

Based on current continuous-strip pickling practice, with some acid wastage, the above fuel charges are about 10*d.* to 1*s.* per ton of pickled strip.

Problems will arise in connection with the separation of the monohydrate from the extremely hot and strongly acidic mother liquor, but no doubt they can be satisfactorily solved by the use of air lifts for removing monohydrate sludge from the burner vessel. The process obviously can be arranged to operate on a continuous basis.

MODIFICATION OF SOLVENT

Thews,[10] de Lattre,[11] and Gehm[4] proposed respectively, the addition to spent liquor of ethyl alcohol, methyl alcohol, and acetone. The solubility of ferrous sulphate is very considerably reduced by these additions, and copperas is precipitated. The resultant

* Coefficient of heat transmission.

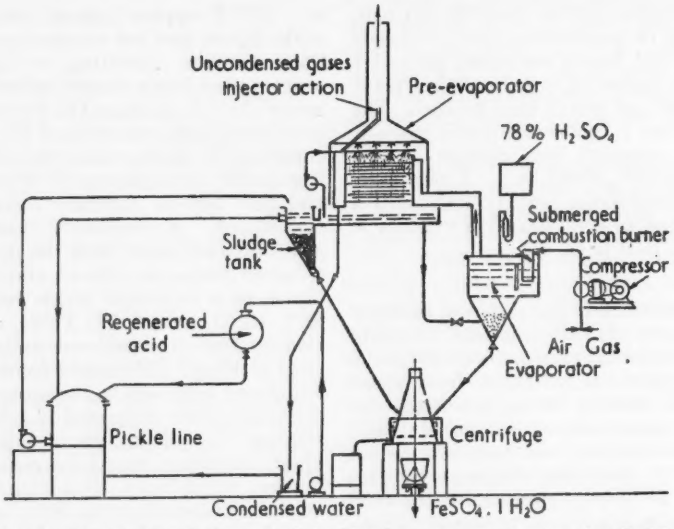


Fig. 9—Diagrammatic layout of the Nordac system of extracting $FeSO_4$

mother liquor containing the addition chemical then requires treatment by fractional distillation for the purpose of recovering the addition agent. There is no practical experience of any of these processes. With relatively expensive addition chemicals, such as those mentioned, it is obvious that the overall economic value is not closely linked with the efficiency of recovery. Gehm suggests the possible need for 99·5% recovery.

Other suggested methods depend on the formation of double salts. Thus, the addition of sodium sulphate to a spent liquor will lead to the precipitation of the double salt of iron and sodium sulphate.[12] Likewise, the addition of ammonium sulphate[13] leads to the precipitation of ferrous ammonium sulphate, a double salt of lower solubility than ferrous sulphate.

DISPOSAL OF COPPERAS

The moderate amounts of copperas produced in this country as the result of spent acid disposal and recovery, are in the main sold for the following purposes :

(1) Manufacture of Prussian Blue and iron-base colours.
(2) Manufacture of certain dyestuffs.
(3) Gas-scrubbing (Ferrox process, etc.).
(4) Weed killers.
(5) Fungicide for timber.
(6) Precipitating sulphides from leather-trade effluents.
(7) Treatment and disinfection of sewers.
(8) Coagulation in sewage plants.

In the event of the steel industry greatly extending the degree to which copperas is produced, the available market will be inadequate. Dumping of copperas at sea has been considered. Roasting is attractive as it converts copperas into sulphurous and sulphuric gases ; these gases are easily convertible to sulphuric acid and iron oxide, which by sintering may be suitable for reduction in the blast-furnace.

If roasting of ferrous sulphate can be proved economic, then the problem of the disposal of spent acid liquor will be substantially solved, the only by-product being oxide of iron. The acid used in pickling would, in fact, be recovered and brought back into circulation. Much investigation has been devoted to the problem in Germany and elsewhere, and many schemes for roasting have been put forward. However, since copperas contains 48% of water, it has the disadvantage of readily dissolving in its own water of crystallization on heating, unless it is dehydrated at a low temperature (50° C.). On the other hand, ferrous sulphate monohydrate can be roasted without this difficulty. Monohydrate, however, is produced from acid-recovery processes as a granular powder, and probably requires briquetting to eliminate the problem of dust. Dust carried over in the sulphurous gases from roasting interferes with the catalyst used for the conversion of the sulphurous gases to sulphuric acid. Finally, comparison must be made between the available sulphur content of copperas (11·5%) and of monohydrate (19%), with pyrites (about 50%) and sulphur, the usual raw materials for sulphuric acid manufacture. Monohydrate roasting has been dealt with in a F.I.A.T. report,[8] and by Spangler[14] and others,[2] and there is some evidence that the operation can be made profitable.

The National Lead Company, U.S.A., have contrary experience. By roasting monohydrate with pyrites (45% on a sulphur basis) in a rotary kiln, the sulphurous gases at 1100° F. were cleaned from solids by (1) a preliminary settling chamber, (2) cyclones and electrostatic precipitator operating at 1000° F., (3) wet scrubbing tower, (4) electrostatic de-mister, (5) charcoal filter, and (6) drying tower, before passing to conventional contact plant. The process has been discontinued because of low recovery and high costs relative to current acid prices, and spent liquor is now more economically shipped to sea.

Nevertheless, under differing economic conditions, where dumping is impossible, and waste heat is plentiful, etc., and taking into consideration the

alternatives of neutralizing, there are many attractions. An integrated steelplant may find it profitable. For small steelplants, it has been suggested that ferrous sulphate could be consigned to a collective roasting plant, but carriage charges would have to be taken into consideration.

Numerous chemical methods of converting copperas into more saleable products have been suggested.[6,15,16] Unfortunately, the potential quantity which would be available would create a surplus of these alternative end-products.

Hoak[6] has suggested that iron sulphate could be used as an alternative to gypsum as an addition agent to cement, for the purpose of regulating the setting time of concrete. Tests have shown that on an SO_3 equivalent basis, iron sulphate possesses, for concrete, the same characteristics as gypsum, tensile and compression requirements being met. The iron gives to concrete a cream to light-brown colour. Ferrous sulphate monohydrate is equivalent to gypsum in SO_3 content, whilst copperas contains about two-thirds. As gypsum is normally used between 2 and 3% by weight of cement clinker, the cement industry could more than comfortably absorb all the ferrous sulphate likely to be produced by the steel industry, provided that costs were favourable.

DISPOSAL OF HYDROCHLORIC SPENT LIQUOR

It is general practice to use hydrochloric acid at considerable strength, at room temperature, and to allow the acid content to fall to quite a low value, without further addition. The usual spent acid therefore contains free hydrochloric acid of the order of 0·5% and a ferrous chloride content of the order of 32–33% w/v. Such liquor, in the quantities in which it is available, is disposed of to oxide and colour manufacturers. Sierp[2] has indicated an interesting acid-recovery cycle, which consists of evaporating the liquor, the ferrous chloride then being reacted with steam and air to yield hydrochloric acid and iron oxide ; the acid is collected by condensation.

PLANT CONSTRUCTION AND OPERATION

Materials of Construction

Materials of construction play a most important part in the handling of acid liquor materials. In one particular plant, steel delivery pipes are lined with rubber, and suction pipes are of ebonite-lined steel. The crystallizer has a hard rubber lining, and the inverted core bottom is lined with ebonite and is fitted with a rubber-covered stirrer and lead cooling coils. The outward valve is rubber-lined and the centrifuge is ebonite-lined. Other plants employ chemical lead linings throughout, which if properly jointed have given excellent service. Silicon iron has proved satisfactory for centrifugal pumps.

The cooling vessels or crystallizers at one plant are steel shells lined with acid-resisting tile plates on bitumen, while in another plant Keebush synthetic-resin linings have proved satisfactory.

Mechanical damage to linings protecting steel constructional work must be avoided, particularly when hot or warm acid liquor is encountered. Settling and other tanks must be cleared out from time to time, and it is wise to protect lined bottoms with a layer of brick to prevent damage.

Details of Life of Plant

Crystallizer linings may have a life of 7 to 10 years. Lead cooling coils have good life, in spite of abrasion by agitators. Coil drains exposed to the full wash of agitators have a shorter life ; in one case it is of the order of some months. Although lead is satisfactory for pipe lines, rubber has been found to be even better in one case and good reports are available for Keebush.

In one plant, metal valves are employed, and crystallizer discharge valves have been made in Monel metal, as they have to withstand considerable abrasion. Centrifuge cages of copper give fair performance. One observation records a throughput of three million gallons in a life of about 6 months. Monel metal is used as an alternative material.

Pumps give varied performances. The ideal would be valveless (to avoid troubles due to inevitable dirt and foreign matter in spent pickle liquor) and glandless. A centrifugal pump approaches the ideal and is available in ceramic material. The Mitchell pump is stated to have performed satisfactorily. A similar performance has been claimed for the Tungstone and Pneu types of pump. The Noristaltic pump has certain points in its favour, but in any case the last three named are subject to troubles associated with the fouling of valves, unless the spent liquor is reasonably clean.

Some observations and precautions on the working of a refrigeration plant have been provided by the author's company. As illustrated in Fig. 6, the tank to receive spent liquor preparatory to reclaiming has a capacity of approximately 5000 gal. and is fitted with a steam coil to maintain temperature to avoid separation of copperas from solution. The spent liquor has a composition approximating 10% H_2SO_4 w/v, 22% $FeSO_4$ w/v, so that the temperature is maintained at 30° C. and upwards. The two crystallizers have a capacity of about 450 gal., and are equipped with stirrers ; cold water circulating through a lead coil cools the liquor in the first cooler to about 20° C. in about half-an-hour. The contents are then run into the second cooler and are refrigerated by circulating iced brine to — 4° or — 5° C. This operation takes about 45 min. and is followed by centrifuging in a 48-in. Broadbent centrifuge.

For a typical run the changing composition of the liquor and the amount of copperas recovered is given below :

Bars pickled during trough life	195·8 tons
Iron increase during trough life due to bars being pickled	1850 lb.
Acid required to dissolve iron (theoretical)	248·5 gal. (BOV)
Acid used in pickling bars ...	252 gal. (BOV)
Acid used per ton of steel pickled	1·29 gal. (BOV)

The reclaiming cycle is as follows :

Volume of liquor processed	3980 gal.
Analysis of liquor processed	10·3% H_2SO_4 w/v, 8·7% Fe w/v
Volume of liquor after reclaiming	3240 gal.

Analysis of liquor after reclaiming	11·49% H_2SO_4 w/v, 3·62% Fe w/v
Shrinkage in volume ...	740 gal.
Actual weight of $FeSO_4.7H_2O$ produced	4·89 tons

Practical Observations

The following points are important in connection with operation and maintenance of plant :

(1) The whole plant should be designed on robust lines, and spares should be available to minimize stoppages in acid recovery which might become embarrassing.

(2) Storage capacity of spent liquor should be ample to deal with all contingencies. Thus, in the case of a number of pickle tanks and particularly where loading is variable, demands on the receiving end of an acid-recovery plant fluctuate widely.

(3) When transferring spent liquor, precautions must be taken to avoid cooling in pipes, etc., as this can easily lead to choking by crystallization.

(4) Pipes should be washed out with water when reclaiming is suspended for a length of time, to avoid crystallization.

(5) The refrigerator should receive frequent attention and servicing.

(6) Crystals caking on cooling coils seriously impede heat transfer, and attention must be paid to this point.

(7) Refrigeration has the advantage that during cold weather it is most unlikely that further crystals will separate out from recovered liquor. This advantage does not apply to straight water-cooling without refrigeration. To obtain highest efficiency from the refrigeration unit (ammonia plant) undue rises in temperature during shut-down periods should be prevented by insulation.

(8) Where effective mechanical agitation is employed in pickling baths, and particularly where it is applied to the pickling of hot-rolled steel bars, the fineness of dirt suspensions makes it difficult to settle out this material by sedimentation, at least in a reasonable space of time.

(9) Where acid dosing is practised, recovered-acid tank storage should be of ample capacity. In refrigeration practice, such storage tanks need not be maintained at equable temperatures.

(10) Centrifuges are likely to require considerable attention and maintenance, and alternative methods of separation of the crystals should be available. Draining trays are said to be satisfactory.

The majority of plants in use in Great Britain employ water-cooling only, some operating on spent mixed acid baths (from 1 to 3% HCl in addition to H_2SO_4). It is usual with water-cooling systems to run to higher iron concentrations in spent liquor, in order to improve the iron removal on cooling.

Performance Data

In a pickle acid recovery cycle a fixed quantity of acid can be assumed to be continually circulating, all acid additions to the bath being converted into iron sulphate. From information received from various sources, Table I has been compiled to show nominal acid saved by the installation of crystallizing acid-recovery plant.

The amounts of iron removed are high with water-cooling, as compared with brine-cooling, owing to the high iron sulphate concentration in the spent liquor, without which water-cooling becomes relatively inefficient. Thus, compare columns *E* and *F* with *A*. When the amount of ferrous sulphate is estimated as a percentage of the original quantity, refrigeration figures are good (*see B, C, D*) and indicate that refrigeration must be employed if it is desired, for technical reasons, to run pickling troughs at medium iron, instead of high iron, concentrations. It is interesting to note that the observed iron concentrations in the mother liquor approximate the theoretical values, indicating that in practice equilibrium conditions can be closely approached on cooling.

Operating Costs

Plant operating costs (per ton of steel pickled) have been kindly provided by three British firms, as follows :

	Firm *A* (Strip)	Firm *B* (Bars)	Firm *C* (Tubes)
Materials (ammonia and salt)	1·5	0·15	1·2
Repairs and maintenance	23	2·9	8·6
Electricity and water ...	2·5	1·8	6·1
Labour and supervision	20	3·5	9·9
Total cost	47	8·35	25·8
Saving in acid	8¾	8·0	14·3

(Figures are in pence)

Table I

PERFORMANCE DATA FOR CRYSTALLIZING ACID-RECOVERY PLANT

Plant Maker:		Kestner	Heastie	Nordac	Zahn	Kestner	Nordac
Cooling Method:		Water, 20° C.	Brine, − 5° C.	Brine, − 4° C.	Brine, 0° C.	Water, 20° C.	Water, 20° C.
		(*A*)	(*B*)	(*C*)	(*D*)	(*E*)	(*F*)
Spent liquor:	H_2SO_4, % w/v	10	10	10	7	10	14 + 1% HCl
	$FeSO_4$, % w/v	24½	23	22	29	36	40
Recovered mother liquor:	$FeSO_4$, % w/v	20	7·5	9½	13·7	19	20
" " " (theoretical)	$FeSO_4$, % w/v	19·8	9·5	10	13·5	18·7	18·3
Made-up to orig. bulk	$FeSO_4$, % w/v	13·7	6·4	8·1	11·25	14·6	14·0
$FeSO_4$ removed (units)		10·8	16·6	13·9	17·75	21·4	26
" " (%)		44	72	63	61	60	65
Nominal acid saving, %		39	39·5	41·5	27·5	30	35

The widely differing operating costs are explained by the variations in surface area and in the acid consumption per ton—highest for strip and lowest for bars. Plant charges have deliberately been omitted as, with the rising prices of lead and of materials of construction generally, such figures based on plant installed some years ago would have little significance. For somewhat similar reasons, sales of copperas by-product have not been taken into account.

CONCLUDING OBSERVATIONS

The paper so far has constituted a survey of current practice, together with general and economic observations, and has shown that widely differing pickling practice necessitates various methods of disposal. The volume of by-products resulting from acid recovery and other treatment tends to be embarrassing, but it is suggested that it may be alleviated somewhat if more attention is paid to the reduction of acid consumed in pickling.

In the presence of an inhibitor, attack on the metal is minimized, as acid consumption is primarily associated with dissolution of scale. Experiments with hot-rolled mild steel, and free-cutting steel rods pickled in conventional batch acid (10% H_2SO_4 w/v, 17% $FeSO_4$ w/v, plus restrainer at 55° C.) and in conventional continuous-strip acid (18% H_2SO_4 w/v, 15% $FeSO_4$ w/v, at 90° C.) demonstrated the following points :

(1) The scale detached in pickling weighed only about 3% of the total loss in weight of the samples, *i.e.*, the major portion of the scale had been dissolved during pickling.

(2) The detached scale took about 24 hr. to dissolve in the batch liquor and about 1 hr. in the continuous-strip liquor.

(3) Scale mechanically detached by straining the specimens dissolved at a much slower rate, *e.g.*, 93% remained undissolved in a period of time equal to the descaling time observed for both acid compositions.

Scale Breakers

The advantage of mechanical detachment of scale before pickling is indicated by the following.

Unless the major portion of the scale is actually detached and separated from the steel surface, before the latter enters the pickling train, scale breaking as commonly practised in strip pickling will have little advantage from the point of view of acid economy or spent acid disposal. Greater degrees of straining in the bending or cracking rolls, together with high-pressure water spray or air blast will assist materially.

The recent introduction of a Wheelabrator in a U.S.A. plant has made possible a travelling speed of 500 ft./min. for strip with a single pickling tank, instead of the usual 300 ft./min., employing four tanks in series.

Adequate scale detachment by cracking rolls could with advantage be applied to the high-production pickling of hot-rolled coil, both acid consumption and the problem of spent acid disposal being reduced to a minimum.

Scale Detached in the Pickle Bath

The scales formed on forgings and hot-rolled bars tend to be less soluble during the pickling process. It is suggested that if relatively deep troughs are designed with a sludge pump, the detached scale might be removed by various means, and separated by a rotary filter, the clean acidic liquor being returned to the pickle tank.

Pickle Acid Waste

Drag-out losses are often high. The amount carried out on steel surfaces can be reduced by employing wetting agents.[17] If a preliminary rinse water is returned to the pickle tank, the major portion of drag-out loss is eliminated. The water-spraying of pickled bars while suspended over the pickle bath had the effect of reducing acid consumption by 20%, and minimized the wash-water disposal problem. The amount of water sprayed was not in excess of the make-up quantity normally required to compensate for evaporation loss.

In the case of strip pickling, high-pressure water sprays applied to both sides of the strip as it leaves the acid, give equally beneficial results ; the condensate from indirect steam heating could usefully be employed for this purpose.

Air blast is being considered to blow drag-out liquor back into the tank. Rubber squeegees are employed in one British plant for a similar purpose.

Spray losses are considerable for a modern high-speed, high-temperature bath, and can be greatly reduced by adequate overhead enclosure with rubber-lined materials and by effectively sealing off at strip entry and exit points in the flow line.

Where direct steam injection is used to heat pickle tanks, it is too often the case that there is a continuous increase in liquor volume with consequent acid loss by overflow. It is usually possible to balance direct with indirect steam heating to maintain approximately constant tank volume.

Finally, mention must be made of the possibility of pickling with a bath substantially saturated with iron, from which sulphate of iron should continuously separate out while pickling proceeds. A British patent[18] claims that ferrous sulphate monohydrate is continuously deposited when pickling at 50° C. with the preferred hydrochloric-acid/sulphuric-acid mixture, a normal pickling time being obtained. A continuous separation and filtration scheme would in theory be all that is necessary to maintain such a ' health recovery ' bath. Numerous problems may arise in practice.

In conclusion, the problem of spent acid pickle disposal is incapable of a simple solution because of widely varying practices in pickling, heating of pickle liquor, varying types and degrees of scale, and differing local conditions. The close co-operation of steelplant engineers, chemical engineers, metallurgists, and the heavy chemical industry, is essential if the question of the disposal of spent acid effluent is to be settled from the broader national angle.

Acknowledgments

Much data and information contained in this paper

have been provided by many friends and firms in the steel industry, to whom the author wishes to express his appreciation. He acknowledges the considerable co-operation received from the Technical Staff of Exors. of James Mills, Ltd., and the assistance rendered by Mr. L. J. Atkins and the Laboratory Staff in the calculations and in the preparation of the illustrations.

References

1. B. A. SOUTHGATE : "Treatment and Disposal of Industrial Waste Waters." Department of Scientific and Industrial Research, London, 1948 : H.M. Stationery Office.
2. F. SIERP : *Stahl und Eisen*, 1938, vol. 58, p. 494.
3. R. D. HOAK and others : *Industrial and Engineering Chemistry*, 1948, vol. 40, p. 2062.
4. H. W. GEHM : *Industrial and Engineering Chemistry*, 1943, vol. 35, p. 1003.
5. M. J. RENTSCHLER : *Iron and Steel Engineer*, 1939, Jan., No. 1, pp. 52–62.
6. R. D. HOAK : *Industrial and Engineering Chemistry*, 1947, vol. 39, p. 614.
7. N. SWINDIN : *Transactions of the Institution of Chemical Engineers*, 1944, vol. 22, p. 56.
8. F.I.A.T. Final Report No. 1117.
9. E. D. MARTIN : *Yearbook of the American Iron and Steel Institute*, 1948, p. 602.
10. E. R. THEWS : F.I.A.T. Final Report No. 808.
11. DE LATTRE : British Patent 491,640 (1938).
12. German Patent 593,269 (1934).
13. British Patent 593,697 (1944).
14. S. F. SPANGLER : *Blast Furnace and Steel Plant*, 1935, vol. 23, p. 319.
15. DE LATTRE : *Sheet Metal Industries*, 1948, vol. 25, p. 252.
16. W. W. HODGE : *Industrial and Engineering Chemistry* 1939, vol. 31, p. 1364.
17. T. P. HOAR : *Sheet Metal Industries*, 1944, vol. 20, Sept., p. 1533,
18. British Patent 562,596.

The Iron and Steel Engineers Group

THE Council, in 1946, appointed an Engineering Committee to form an Iron and Steel Engineers Group, and to organize Meetings and Discussions on the problems of Iron and Steel Works Engineering. The composition of the Engineering Committee, as approved in April, 1949, is as follows :

MR. F. W. CARTWRIGHT (*Chairman*)	Steel Company of Wales
MR. J. BUCHANAN	Priest Furnaces, Ltd.
MR. F. B. GEORGE	Consett Iron Co., Ltd.
MR. D. C. HENDRY	Messrs. Stewarts and Lloyds, Ltd.
MR. J. F. R. JONES	John Summers and Son, Ltd.
SIR ANDREW McCANCE, F.R.S. (*ex officio*)	Colvilles Ltd.
MR. H. H. MARDON (*ex officio*)	The British Iron and Steel Research Association
MR. JAMES MITCHELL, C.B.E. (*ex officio*)	Messrs. Stewarts and Lloyds, Ltd.
MR. G. A. PHIPPS	Messrs. Guest Keen & Nettlefolds, Ltd.
MR. W. J. POOL	The British Thomson Houston Co., Ltd.
MR. L. ROTHERA	Colvilles Ltd.
MR. F. SANITER	The United Steel Companies, Ltd.
MR. I. S. SCOT-MAXWELL (*ex officio*)	British Iron and Steel Federation
MR. B. THORNTON	The Wellman Smith Owen Engineering Corporation, Ltd.
MR. W. UDALL	The Brightside Foundry and Engineering Co., Ltd.
MR. P. WRIGHTSON	Head, Wrightson and Co., Ltd.

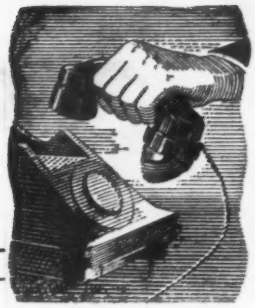
Membership of the Group is open to all Members of the Institute without additional fee.

The Iron and Steel Engineers Group collaborates closely with Local Societies affiliated to The Iron and Steel Institute, and with other British and Foreign Engineering Institutions.

A special section of the monthly Journal is devoted to the proceedings of the Group, and from time to time are published descriptions of new plant.

The programme and notices of the activities of the Group are announced in the News Section of the Journal.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1949

The Annual General Meeting was held in London, on Wednesday and Thursday, 27th and 28th April, 1949.

The Members' Luncheon was held at the Dorchester, Park Lane, W.1, on Thursday, 28th April:

The Toast to "The Iron and Steel Institute and Industry" was proposed by His Excellency the Norwegian Ambassador, Mr. Prebensen; and the response was made by Sir Andrew McCance, LL.D., D.Sc., F.R.S., President of The Iron and Steel Institute.

The Toast to the "Guests" was proposed by Mr. G. H. Latham, Vice-President of The Iron and Steel Institute, and the response was made by Sir Charles Darwin, K.B.E., F.R.S., Director of The National Physical Laboratory.

A report of the Meeting and of the speeches at the Luncheon will appear in a later issue of the *Journal*.

Autumn Meeting, 1949

The Autumn Meeting of the Institute will be held in London on the 9th and 10th November, 1949.

Changes on Council, 1949

Capt. C. A. Ablett, O.B.E., B.Sc., M.Inst.C.E., of the Cooper Roller Bearings Co., Ltd., King's Lynn, Norfolk, has been made an Honorary Vice-President of the Institute.

Dr. David Binnie, Ph.D., of the Lancashire Steel Corporation, Ltd., Irlam, near Manchester, has become an Honorary Member of Council on his election as President of the Manchester Metallurgical Society in succession to Mr. A. H. Goodger, M.Sc.

NEWS OF MEMBERS

▶ Captain S. T. Binstead has retired from the post of Trade Commissioner to the Government of Mysore. Captain Binstead spent many years in India and in other parts of the East, and then represented the Mysore Government in London for about ten years. During this period he made many friends in the steel and engineering industries. Although he relinquishes the post of Trade Commissioner, Captain Binstead will in future be taking care of certain personal interests of H.H. Maharajah of Mysore, and will shortly be visiting Mysore in this connection.

▶ Mr. R. S. Brown, chief metallurgist at Messrs. Rylands Bros. Ltd., Warrington, Lancs., has been awarded the Annual Medal of the Wire Association of America, for 1948, for the most meritorious paper on wire manufacture or fabrication. The medal will be presented at the Annual Luncheon of that Association, to be held at La Salle Hotel, Chicago, Ill., on 19th October, 1949.

▶ Mr. K. S. Ganapati has been appointed, by the Defence Department of the Government of India, Assistant Works Manager (under training) at the Ordnance Factory, at Katni.

▶ Professor J. N. Greenwood has relinquished the appointment of Honorary Corresponding Member for Australia to the Council of the Institute of Metals, an appointment he has held for the past twenty-three years.

▶ Mr. E. Hallas, Director of the Brightside Foundry and Engineering Co., Ltd., of Sheffield, has joined the Board of Messrs. Buckley and Taylor, Ltd., Castle Ironworks, Oldham, Lancs.

▶ Mr. H. Hoffstedt has been elected a Member of the American Society for Metals. As from 1st May, 1949, Mr. Hoffstedt has been appointed sales engineer of the Oy Vuoksenniska Ab of Helsingfors, Finland.

▶ Mr. E. L. James has relinquished the post of assistant metallurgist at Messrs. Forgings and Presswork, Ltd., Birmingham, and is now assistant metallurgist at Messrs. John Garrington and Sons, Ltd., at Bromsgrove, Worcestershire.

▶ Mr. Russell Jay left The Morgan Crucible Co., Ltd., of Battersea, S.W.11, on April 1st, 1949, to take up a position on the Liaison Staff of the British Non-Ferrous Metals Research Association.

▶ Mr. A. B. Kinzel, President of the Union Carbide and Carbon Research Laboratories, Inc., N.Y., has been elected Vice-President of the American Institute of Mining and Metallurgical Engineers.

▶ Mr. J. A. Matthews, of the Engineering Department of the Eagle Star Insurance Co., Ltd., has been elected a Member of The Institution of Mechanical Engineers.

▶ Dr. R. B. Mears has been awarded the Speller Award by the National Association of Corrosion Engineers of the U.S.A.

▶ Mr. J. A. Naismith has resigned the position of steel plant manager with Messrs. J. Lysaght, Ltd., Scunthorpe, and has taken up the position of chief research metallurgist with Messrs. W. T. Flather, Ltd., of Sheffield.

▶ Professor H. O'Neill, Professor of Metallurgy at University College, Swansea, will present the Edward Williams Lecture at the Annual Conference of the Institute of British Foundrymen which opens at Cheltenham Spa on the 14th June, 1949.

▶ Mr. W. Sandham has joined the staff of the furnace department of Messrs. Thompson Bros. (Bilston), Ltd., Staffs.

▶ Mr. Onkar Dayal Shrivastava has been appointed technical assistant, Directorate General of Industries and Supplies, Government of India, New Delhi, India.

Obituary

Mr. J. H. Cummings, of 16 The Avenue, Lincoln, on the 3rd January, 1949.

R. S. Brown

W. G. Cameron

D. M. Brasher

A. Jackson

CONTRIBUTORS TO THE JOURNAL

R. S. Brown, M.B.E., F.I.M., A.M.C.T.—Chief Metallurgist at Messrs. Rylands Bros., Ltd., and the Whitecross Co., Ltd., of Warrington, of which latter company he is also a director. Mr. Brown joined the firm of Rylands Bros., in 1915, and served in the general office, drawing office, and test house before joining the laboratory as metallurgical assistant to the late Mr. A. E. Atkins, M.Sc. Mr. Brown received his technical education at the Manchester College of Technology, of which he is an Associate in both metallurgy and chemical technology. In 1920, he gained the City and Guilds First Prize and Medal in Iron and Steel Manufacture.

Mr. Brown is a member of the Mechanical Working Committee of the British Iron and Steel Research Association, and is a member of the British Non-Ferrous Metals Research Association, serving on research committees connected with zinc and galvanizing. He also serves on a number of British Standards Institution Committees. Mr. Brown is a member of the Wire Association of America, to which he has presented technical papers connected with the wire industry. He has been awarded the Annual Medal Award for 1948 of that Association, for the most meritorious paper on wire manufacture or fabrication presented during the year.

Mr. Brown is a Past-President of the Manchester Metallurgical Society, and is a Member of Council of the Liverpool Metallurgical Society. He has been a member of The Iron and Steel Institute since 1932.

W. G. Cameron—Assistant Melting Shop Manager at the Lanarkshire Steel Co., Ltd., Mr. Cameron was educated at Hamilton Academy and the Royal Technical College, Glasgow. His entire working life has been spent with the Lanarkshire Steel Co., Ltd., where in 1927 he was appointed chief chemist and in 1937 he was appointed chief chemist and metallurgist. Mr. Cameron took up his present position in 1946.

A. Jackson, A.Met., F.I.M.—Works Manager (steel), Appleby-Frodingham Steel Co., Ltd. Mr. Jackson was born at Scunthorpe in 1905, and graduated from Sheffield University in 1925. In the same year he was awarded the City and Guilds of London Institute's Full Technological Certificate (iron and steel manufacture). From 1929 to 1936 he was part-time lecturer in metallurgy at Scunthorpe Evening Technical School. He is a member of the Metallurgical Advisory Committee of the City and Guilds of London Institute. In 1942 he was awarded the Williams Prize by The Iron and Steel Institute. Mr. Jackson is Vice-President of the Lincolnshire Iron and Steel Institute. He joined the Appleby-Frodingham Steel Company in 1920 where he has been assistant chemist, metallurgist, assistant melting shop manager, slab mill manager, works metallurgist, melting shop manager, melting shop superintendent, and finally, works manager.

From 1945 to 1946 he was in Germany on loan to the Control Commission, working on the technological investigation of iron and steel plants.

Miss D. M. Brasher, B.Sc., A.R.I.C.—Senior Scientific Officer in the Chemical Research Laboratory of the Department of Scientific and Industrial Research, Teddington. Miss Brasher was born in 1906, and educated at the County High School, Aldershot, and King's College, London. She obtained a degree in Chemistry (first-class honours) in 1927, and received the Daniell Research Scholarship awarded by the college. During the following year Miss Brasher was engaged on electrochemical research. From 1928 to 1945 she was in the Physico-Chemical Section of the Laboratories of Messrs. J. Lyons and Co., Ltd., where she gained experience in a wide variety of techniques, such as spectrographic, polarographic and X-ray diffraction methods. Miss Brasher took up her present position in 1946, and she has since been carrying out electrochemical studies of corrosion in association with Dr. Wormwell.

T. F. Russell, A.Met., F.I.M.—Senior Metallurgist at the English Steel Corporation, Ltd. Mr. Russell's photograph appears on this page, his biography was published in the May issue of the *Journal*.

R. W. Treasure, M.J.I.E.—Engineering Executive in the auxiliary rolling mill department of the Wellman Smith Owen Engineering Corporation, Ltd., London, and Darlaston, South Staffs. Mr. Treasure was born in 1916 and educated at Sutton, Surrey. In 1928, he obtained a scholarship to pursue his engineering studies at the Wimbledon Technical College. After serving an apprenticeship in general engineering and machine tool produc-

T. F. Russell

R. W. Treasure

tion he joined the staff of Messrs. Barter and Sons, Ltd., specializing in industrial heating and related metallurgical equipment. In 1939, he was transferred to the Ministry of Supply, Woolwich, under the direction of the Chief Mechanical Engineer, and was responsible for equipping twenty-six Royal Ordnance Factories with steelmaking, metallurgical, and rolling-mill plant.

Mr. Treasure joined the sheet mill equipment section of the Wellman Smith Owen Engineering Corporation, Ltd., in 1943 and subsequently was appointed to his present position. He is now concerned with the development, design and construction of strip normalizing lines, descaling and decarburizing lines, and wide strip continuous pickle lines.

IRON AND STEEL ENGINEERS GROUP

The TENTH MEETING of the Iron and Steel Engineers Group will be held at the offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 22nd June, 1949. Particulars of the papers to be presented and discussed appeared in the *Journal* for May, p. 107.

AFFILIATED LOCAL SOCIETIES

Swansea and District Metallurgical Society

The List of Officers for the session 1949–50 is as follows :

President

ROOSEVELT GRIFFITHS, M.Sc., F.I.M.

Vice-Presidents

H. J. THOMAS — L. A. S. PERRETT, F.I.M.

Hon. Treasurer — U. WILLIAMS

Joint Hon. Secretaries — H. A. COOKE; M. J. A. THOMAS, B.Sc.

Council

D. L. BLEWITT — F. MILLS, M.I.Mech.E.
H. M. BOWEN — D. G. LEWMAN
R. G. DAVIES — Prof. H. O'NEIL, M.Met., F.I.M.
R. W. EVANS, M.Met. — R. WALKER

Captain H. Leighton Davies, C.B.E., has been appointed to represent The Iron and Steel Institute on the council.

NEWS OF SCIENCE AND INDUSTRY

Conference on Welding as an Aid to the Saving in Steel and Man-Power

A conference on "Welding as an Aid to the Saving of Steel and Man-Power," organized by the British Welding Research Association and the Institute of Welding, was held at Ashorne Hill, Near Leamington Spa, on 22nd to 25th March, 1949. Some two hundred executives, engineers, and designers attended the conference, which was opened by Sir Andrew McCance, F.R.S.

Conclusions formed at the conference are that :

Whilst a considerable saving is, in fact, being achieved by the application of welding to machine-tool construction, a wider knowledge of this saving is essential.

The advantages of welding, of correct welded design, and of the available welding processes and production methods, should be publicized as widely as possible throughout the steel-using industries.

Designs must be prepared specifically for welding.

Industrial establishments must be laid out primarily for welded construction.

Maximum advantage should be taken of the versatility of welding in maintenance work, and for reclaiming damaged or worn parts.

Further advantage should be taken of the opportunities for economic design offered by welding. For example, the plastic design method applied to structures would effect considerable saving in steel.

Research should be pressed forward, and new research work initiated, into new design methods which would give further economies in welded structures.

Automatic and semi-automatic welding methods should be applied whenever practicable.

Steelmakers should be urged to roll those special sections which would assist in the application of welding to better advantage in structures and ships.

The use of weldable quality high-tensile steels should be extended.

Research in new weldable alloy steels should be vigorously pressed forward.

Steel of low notch-sensitivity is an urgent requirement.

The economy which can be achieved in welded construction by the use of light-gauge sections should be further developed.

Continued efforts should be made to improve the quality of production welding.

The necessity of the application of stress-relieving to reduce costs should be the subject of research.

It was decided that all papers presented to the conference should be published in the *Transactions of the Institute of Welding*, and in *Welding Research* ; and that a committee be formed, comprising Dr. Paterson, Mr. Roberts, and Dr. Taylor, with power to co-opt, to consider the best way to disseminate information on the best current welding practice.

Symposium on "The Scientific Study of the Cutting of Metals"

From November 15th to 18th, 1948, a symposium was organized by the Société Française des Mécaniciens, on the scientific study of the cutting of metals. About forty papers were presented at the meetings, and among the aspects discussed were : machinability and grindability, turning, drilling, and milling ; the formation of chips and surface condition ; metal cutting in the workshop ; measurement and measurement appliances ; metallurgical aspects.

The following British papers were presented :

KENNEFORD : "A Rapid Machinability Test"
ARNOLD : "Vibration Phenomena in the Cutting of Metals"
ECKERSLEY : "Applications of Wimet to Metal Cutting"
WRAGGE : "Observations on the Variation of Machinability of Steel in Relation to the Dimensions of the Bar."

Festival of Britain, 1951

The Council of Industrial Design has been charged by the Government with the responsibility for the selection of all contemporary manufactured articles to be shown in the 1951 exhibitions and festivals.

The precise methods of selection of manufactured goods, in their many categories, have not yet been decided, though the principle of selection can be clearly stated : the highest standard of contemporary design, which must embrace functional, aesthetic, and engineering qualities taken together.

Before any selection is possible there must be some assessment of the products available. To this end the Council of Industrial Design has opened what it calls its "1951 Stock List," which is a photographic card index of all manufactured products of such a standard of

excellence as could qualify them for display in 1951, or at least for submission to a panel of selectors.

In order that this Stock List may be widely representative of all branches of industry and may represent the greatest number of firms in each branch, manufacturers are urgently invited to send, to the Chief Industrial Officer of the Council of Industrial Design, photographs, catalogues, leaflets, or samples illustrating those items which they consider to be their best work, bearing in mind that best selling lines are not necessarily those which reflect the greatest credit on a company.

The Council will also welcome news of new processes and new materials which if brought to the notice of industrial designers could be exploited in time to enrich the " 1951 Stock List."

The Institution of Mining and Metallurgy

The Second Sir Julius Wernher Memorial Lecture of the Institution on " The Effect of Impurities on the Properties of Metals " will be delivered by Dr. C. H. Desch, F.R.S., on 6th July, 1949, at The Royal Institution, 21 Albemarle Street, London, W.1, at 5 P.M.

Department of Scientific and Industrial Research

His Majesty the King has been graciously pleased to appoint Sir BEN LOCKSPEISER, F.R.S., Secretary to the Committee of the Privy Council for Scientific and Industrial Research, as from 1st May, 1949. During the First World War Sir Ben Lockspeiser carried out investigations on dysentery in connection with the Burroughs and Wellcome Laboratory, and subsequently held appointments as scientific officer on research with the Royal Aeronautical Establishment, the Air Ministry, and the Ministry of Aircraft Production ; and in 1946 became chief scientist at the Ministry of Supply.

Memoranda

▶ Professor LESLIE AITCHISON has resigned his post as Professor of Industrial Metallurgy at Birmingham University, on account of ill-health.

▶ Mr. JAMES RHYNE KILLIAN, jun., was inaugurated as tenth president of the Massachusetts Institute of Technology at Cambridge, Massachusetts, on 2nd April, 1949.

▶ Dr. F. MEYER has been appointed chairman of the South African Iron and Steel Corporation.

▶ The Power-Gas Corporation, Ltd., Ashmore, Benson, Pease and Co., Ltd., Stockton-on-Tees, have acquired the Lease of the new North-East Trading Estates factory in Bowesfield Lane, Stockton. The Stockton Companies, the first tenants of the new factory, state that it will be specially equipped for the efficient production of heat exchangers, industrial fume and dust control and recovery plant, pneumatic conveyors, and general light assembly work.

▶ Messrs. Head, Wrightson and Co., Ltd., of Thornaby-on-Tees, inform us that they have acquired the businesses of : Messrs. F. J. and L. Dean, of Slough, Bucks., Messrs. Aldean Designs, Ltd., of Slough, Bucks., and Messrs. D. J. Hawkins and Sons, Ltd., of Henley-on-Thames, Oxon. These businesses will be amalgamated with the Head, Wrightson Light Alloy Structures, Ltd., and will be known as Head, Wrightson Aldean, Ltd., with headquarters at Slough, Bucks.

Changes of Address

▶ As from Tuesday, 19th April, 1949, the Head Office of the Woodall-Duckham Vertical Retort and Oven Construction Company (1920) Ltd., is at Woodall-Duckham House, 63–77, Brompton Road, London, S.W.3.

▶ The director and staff of the Mechanical Engineering Research Organization of the Department of Scientific and Industrial Research, moved into Rex House, Regent Street, London, S.W.1, on 17th January, 1949.

▶ The head offices of The Mond Nickel Co., Ltd., are Sunderland House, Curzon Street, W.1, as from 28th March, 1949.

▶ The address of the Water-Tube Boilermakers' Association is 8 Waterloo Place, Pall Mall, London, S.W.1, as from 7th February, 1949.

DIARY

4th–6th June—CONGRÉS NATIONAL DES INGÉNIEURS DE FRANCE—Toulouse.

13th–20th June—SPANISH INDUSTRIAL ENGINEERS—Meeting—San Sebastian.

14th June—INSTITUTE OF BRITISH FOUNDRYMEN—Annual Conference—Cheltenham Spa.

15th–17th June.—FOURTH INTERNATIONAL GAS CONFERENCE, The Institution of Civil Engineers, Great George St., London, S.W.1.

22nd June—IRON AND STEEL ENGINEERS GROUP—Tenth Meeting—4 Grosvenor Gardens, London, S.W.1.

28th–30th June—INSTITUTION OF NAVAL ARCHITECTS—Summer Meeting—Royal Society of Edinburgh, 22 George Street, Edinburgh.

6th July—THE INSTITUTION OF MINING AND METALLURGY—Sir Julius Wernher Memorial Lecture, " *The Effect of Impurities on the Properties of Metals,*" by Dr. C. H. Desch, F.R.S.—The Royal Institution, 21 Albemarle Street, London, W.1, 5 P.M.

7th–8th July—INSTITUTION OF MINING AND METALLURGY—Symposium on the Refining of Non-Ferrous Metals—The Royal Institution of Chartered Surveyors, Great George Street, London, S.W.1, 10 A.M. to 5 P.M.

13th July—INSTITUTE OF WELDING—Annual General Meeting—The Institution of Civil Engineers, Great George Street, London, S.W.1, 2.30 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the May, 1949, issue of the *Journal*, p. 108.)

TRANSLATIONS AVAILABLE

No. 378 (French). P. COHEUR and A. HANS : " Direct and Graphical Spectrographic Analysis with a Single Apparatus." (*Revue Universelle des Mines*, 1949, Series 9, vol. 5, Feb., pp. 63–68.)

No. 379 (German ; abridged), E. KARWAT : " The Planning of Large-Scale Oxygen Plants." (*Stahl und Eisen*, 1948, vol. 68, Dec. 2, pp. 453–461). (Translation made available through the courtesy of the Research and Development Department, The United Steel Companies, Ltd., Stocksbridge, near Sheffield.)

CHARGES FOR COPIES OF TRANSLATIONS—For the above translations a charge will be made of £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS

	PAGE
Fuel—Preparation, Properties, and Uses	229
Temperature Measurement and Control	229
Blast-Furnace Practice and Production of Pig Iron	230
Production of Steel	230
Foundry Practice	231
Heating Furnaces and Soaking Pits	233
Forging, Stamping, Drawing, and Pressing	233
Rolling-Mill Practice	234
Machinery for Iron and Steel Plant	234
Welding and Flame-Cutting	234
Cleaning and Pickling	235
Protective Coatings	236
Properties and Tests	237
Metallography	242
Corrosion	243
Book Notices	246
New Publications	248

FUEL—PREPARATION, PROPERTIES, AND USES

Combustion Studies Using the Golay Photothermal Detector with an Infrared Monochromator. J. T. Agnew. (Transactions of the American Society of Mechanical Engineers, 1949, vol. 71, Feb., pp. 107–114).

Determination of Losses Due to Unburned Combustible Particles in Pulverized Coal Furnaces. R. Doležal. (Strojnický Obzor, 1947, vol. 27, Apr., pp. 165–169). [In Czech]. For pulverized coal the losses due to unburned combustible residue remain reasonably low up to mean ash contents of about 50%. The causes of these losses are : (1) With particles very high in ash the fuel is enclosed in an ash shell which prevents contact between the non-volatile fuel substance and the air, and these losses are the larger, the larger the pulverized grains ; (2) the ash of the individual particles melts after partial combustion of the fuel substance and it forms a plastic shell which prevents further burning of the enclosed coal substance ; (3) if the combustion chamber is not properly designed, or if the grinding and drying of the coal are not correctly carried out losses increase still further ; and (4) a decrease in the boiler load may also lead to further loss. Only the losses (1) and (2) are considered in the paper. There are two types of ash, one consisting of minerals contained in the original vegetable matter and the other of external admixtures. During grinding, the heterogeneous structure is broken up into particles consisting predominantly of pure carbon and others consisting almost entirely of uncombustible admixtures. This process is more efficient with decreasing size of the pulverized fuel. The losses due to unburned combustible particles are a product of three functions : τ (a) of the mean ash content, ϕ (M) of the grain size, and ψ (N) of the instantaneous boiler load, *i.e.*, $z = K \cdot \tau\,(a) \cdot \phi\,(M) \cdot \psi\,(N)\%$. The grains containing ash arising only from the carbonized vegetable matter will burn almost completely, whilst the nonvolatile parts of the grains containing mainly ash (of external origin) will remain unburned, and this is taken as a basis for determination of the function ϕ (M). The product $K \cdot \phi\,(M) \cdot \psi\,(N)$ is usually determined experimentally, in a furnace which is similar to the one planned. Fuel of the same origin and a lower ash content should be used for the test, and boiler load and fineness of grinding should also be the same as in the planned installation. τ (a) = a/(100−w−a), where : a = mean ash content %, w = water content in %. The loss values obtained by this formula are in good agreement with empirically measured values.—E. G.

Pressure-Gas Burners for Industrial Furnaces. E. H. Steck. (Iron and Coal Trades Review, 1949, vol. 158, Mar. 11, pp. 511–512). Brief illustrated descriptions are given of high-pressure and low-pressure gas burners which are designed to mix gas and combustion air in a mixing chamber to facilitate complete combustion with a short flame. A burner block, arranged at the end of the burner tube, protects the mixing chamber against heat and helps to keep the flame small. Only sufficient chimney draft to remove waste gases is required.—J. C. R.

Flow Systems. A Review of Data on Pressure Losses. J. A. Leys. (British Iron and Steel Research Association : Iron and Steel, 1949, vol. 22, Feb., pp. 39–43 ; Mar., pp. 85–89). This is a review of data on pressure losses of fluids ; and it deals with losses in elbows and branches and losses due to a change of section. It is stated that an estimate of the loss factor of a non-standard configuration may be obtained by the use of a model of the system working at approximate Reynold's similarity. The loss factor F is defined as :

$$F = 2g.\Delta H/(\overline{V})^2 = 2\Delta p/\rho(\overline{V})^2 + [1 - (\overline{V^1}/\overline{V})^2]$$

J. C. R.

New Methods of Cleaning Coal. F. Špetl. (Báňský Obzor, 1948, vol. 2, Nov., pp. 161–166 ; Dec., pp. 181–188). [In Czech]. The author describes the various methods of cleaning coal by flotation in heavy media and compares their merits. The process used by the Dutch firm Stamicarbon is described in detail.—E. G.

Coal Preparation for the Production of Coke to be Used in a 2000 Ton Blast Furnace. E. J. Gardner. Blast Furnace and Coke Association of the Chicago District and Eastern States Blast Furnace and Coke Oven Association : Blast Furnace and Steel Plant, 1948, vol. 36, Dec., pp. 1463–1464). Finding the quality of its coke being reduced by the increase in mechanical mining with a consequent increase in the ash content, the Inland Steel Co. has installed its own coal cleaning plant. The product from this, containing 4% ash and 0·75% sulphur will be mixed with other coal containing 1·5% ash and 0·65% sulphur, in the proportion of 70 : 30. Coke from such a mixture will have 6% ash and 0·62% sulphur and its resistance to crushing and abrasion should be adequate for blast-furnace use.—J. P. S.

Volume of Porous Solids in the Lump and Crushed States. M. Hofsäss. (Gas- und Wasserfach, 1948, vol. 89, pp. 139–142 : [Abstract] Monthly Bulletin of the British Coal Utilisation Research Association, 1948, vol. 12, Dec., p. 444). The pressure of a volume of gas in a vessel is measured with and without the material to be tested. The apparatus is described and also its application to coke testing.

TEMPERATURE MEASUREMENT AND CONTROL

Automatic Temperature Control of Industrial Processes. E. B. Estabrook. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 139–145). The principles of temperature control systems for industrial processes are explained and some typical instruments and circuits are described.—R. A. R.

Process Reactions Encountered in Automatic Temperature Control Installations and Some Means of Maintaining the Desired Balance or Condition within the Process with Reduced Lag. E. Ferner. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 146–149). Wheelco electronic temperature recording and fuel control systems are described and discussed.—R. A. R.

Automatic Chemical Process Control. H. M. Schmitt. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 150–159). The temperature and pressure controlling systems which are described are of the electronic-pneumatic type, and the examples given include installations for controlling a plating bath, a rotary kiln, and drying ovens.—R. A. R.

A Continuously Balanced Thermoelectric Potentiometer Pyrometer. H. M. Schmitt. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 160–162). A continuously balanced electronic potentiometer pyrometer, in which the small D.C. potential from the thermocouple is converted into A.C. and amplified, is described. The instrument is very robust, and can be used where there is considerable vibration.—R. A. R.

Industrial Application of Automatic Regulators for Temperature, Pressure, Moisture, etc. J. J. Studer. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 163–167). Two electrically operated control systems are described. One is the Rheo Differential Regulating system operated by a resistance which varies with the temperature; the other controls the level of water in a feed tank.—R. A. R.

Temperature Measurements on Liquid Steel. S. Fornander. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 233–237). Experiments with quick-immersion thermocouples for measuring the temperature of liquid steel are described. A pyrometer of British design gave good results in high-frequency induction furnaces. Some modifications were incorporated so as to prevent the evolution of gas from any parts of the pyrometer when used in open-hearth and electric arc furnaces. Good reproducibility was obtained and up to fifty immersions could be made with the same hot junction without change in the e.m.f. of the thermocouple.—R. A. R.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Off-Site Blast Furnace Construction. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 825–826: Iron and Steel Engineer, 1948, vol. 25, Nov., pp. 105–106). While an old furnace was still in blast, the shell of a new furnace was constructed on a trestle close by. After the old furnace was dismantled new foundations were prepared on the same site and the new shell moved 131 ft. on a travelling platform to the site. The new furnace, which has a daily capacity of 1400 tons, started operation 95 days after the old furnace was blown out. The method of moving the shell and its erection on to its permanent columns are described.—J. C. R.

American Brake Shoe Making Steel Plant Castings in New Plant. (Blast Furnace and Steel Plant, 1948, vol. 36, Dec., pp. 1472–1474, 1488). A number of non-ferrous castings made in the foundry of the American Brake Shoe Co. find use in iron and steel works, such as copper tuyeres and cooling plates, bronze structural castings, locomotive and wagon bearings, bronze mill-bearings, and babbitt metal.—J. P. S.

Jet Caster Speeds Tap Hole Opening. B. S. Old and A. R. Almeida. (Eastern States Blast Furnace and Coke Oven Association: Iron Age, 1949, vol. 163, Feb. 17, pp. 85, 162; Steel, 1949, vol. 124, Feb. 21, pp. 108, 110–111). A new method for opening tapholes in blast-furnaces, open-hearth furnaces, and other types of furnace uses a shaped explosive charge, of the "hollow-charge" type. The high-speed jet which it projects can penetrate up to 8 in. of cold cast iron. The explosive can only be detonated by use of a blasting cap, and it will not explode under the influence of heat or percussion.—J. P. S.

A Spark in Steel. (Fortune, 1948, Dec., pp. 95–101, 174, 176, 179–182, 184, 186). The blast-furnace is not a modern instrument, but the relatively recent innovation of high-top-pressure working is considered to be either a component part or the forerunner of the revolution that must be made if steelmaking technology is to progress. An outline is given of the blast-furnace process, special reference being made to solution-loss reactions, and the origins, early applications, present practice, and possible future developments of high-top-pressure operation are discussed. The production of iron direct from its ores without the use of coke is also considered, and the paper, which is copiously illustrated, concludes with a discussion of the technical and economic aspects of oxygen-enriched blast as compared with those of high-top-pressure working; this comparison is favourable to the latter, but oxygen-enrichment and high top pressure should not be regarded as competitive but as complementary.—J. R.

PRODUCTION OF STEEL

Developments in the Iron and Steel Industry during 1948. I. E. Madsen. (Iron and Steel Engineer, 1949, vol. 26, Jan., pp. 94–117). The author discusses advances in steelmaking and ironmaking techniques during 1948 and gives details of new plant installed during the year.—J. C. R.

New Melting Shop at Appleby-Frodingham. (British Steelmaker, 1949, vol. 15, Jan., pp. 10–14). A brief illustrated account is given of the melting shop at the Appleby-Frodingham Steel Company's works which commenced operations in 1947. It incorporates a 600-ton active metal mixer, two 300-ton tilting furnaces, two 140-ton ladle cranes, and two 4-ton ground type furnace chargers.—R. A. R.

Open-Hearth Plant at Clydesdale Steelworks. (Engineering, 1949, vol. 167, Feb. 11, p. 127). **Open-Hearth Furnaces for a Steel and Tube Works.** (Engineer, 1949, vol. 187, Feb. 4, pp. 139–140). **Steel for Tubes. New Furnaces at Stewarts and Lloyds Clydesdale Works.** (Iron and Steel, 1949, vol. 22, Feb., pp. 49–51). A description is given of four new 60-ton open-hearth furnaces at the Clydesdale Works of Stewarts and Lloyds, Ltd. They were designed for producing high-quality, relatively light-weight, bottom-cast ingots for tube-making. The regenerators, slag pockets, and uptakes are considerably larger than usual. The slag pockets are designed for a continuous run of at least 600 heats. The furnaces have port ends of the Venturi type and are fired with producer gas.

Power Station of the Largest European Iron and Steel Plant. H. Hermanns. (Blast Furnace and Steel Plant, 1948, vol. 36, Dec., pp. 1484–1485). The coking plant and power station of the Brunswick Iron and Steel Plant are described. Two by-product coke-oven batteries produced coke for the blast-furnaces; the surplus gas, together with some blast-furnace gas, was distributed by pipeline to other cities in Germany. The rest of the blast-furnace gas was used to generate steam for the blast-furnace blowers, to heat the hot-blast stoves, and, mixed with coke-oven gas, to heat the open-hearth furnaces. In emergencies, blast-furnace and coke-oven gas could be used in the power-station furnaces, which normally used powdered coals. The power generated was 230,000 kW. at 10,000 V.—J. P. S.

Factors Affecting the Quality of Rimming Steel Ingots. J. A. Warchol. (Blast Furnace and Steel Plant, 1948, vol. 36, Dec., pp. 1461–1462, 1469). In a rimming steel satisfactory for fabrication into rod, wire, strip, and sheet, the blowhole must be located sufficiently far from the ingot surface to avoid internal oxidation during reheating. For gas evolution during solidification to meet this condition (*a*) furnace practice (1) must provide good bath agitation through correct carbon control, (2) must include good slag control methods which will simultaneously supply enough oxygen to the metal and not necessitate much deoxidation in the ladle, (3) must provide equilibrium conditions at tapping; (*b*) deoxidation practice must take into account tap slag analysis, tap carbon, the analysis of the final product, the temperature of the metal and the mould size; (*c*) pouring practice must not retard rimming; and (*d*) moulds must be properly dressed and free from moisture and scale.—J. P. S.

Canadian Steel. Open-Hearth Practice at Algoma. N. F. Dufty. (Iron and Steel, 1949, vol. 22, Feb., pp. 45–48). An account is given of steelmaking practice at the works of the Algoma Steel Corporation, Sault Ste. Marie, Canada.—J. C. R.

Fast Open-Hearth Charging. (Iron and Steel Engineer, 1949, vol. 26, Jan., pp. 126–127). **Design Suggests Means for Reducing Time of Open Hearth Heats.** (Steel, 1949, vol. 124, Jan. 31, pp. 68, 71). Details are given of two inventions by F. W. Gumpp. The first is intended to facilitate fast charging of the open-hearth furnace. A cross-section illustration is given of the proposed new furnace which generally follows conventional design except that it is suggested that generator chambers might be constructed at ground level at each end of the furnace. The main roof of the furnace, however,

between knuckles, bears on skewbacks which in turn are carried on vertical plunger rods which are parts of hydraulic jacks. Thus, the main roof section between knuckles can be raised and lowered. An overhead crane may be used instead of hydraulic jacks. Charging platforms extend for the entire length of the movable roof section and run along each side of the furnace, the inner edges being pivoted to a supporting column and the outer edges supported by the plunger elements of jacks in a second hydraulic system. Auxiliary equipment and charging procedure are described. The second innovation in open-hearth furnace design concerns the method of tapping. The new design of furnace is provided with a pouring nozzle built into the bottom of the furnace. The arrangement of the taphole is illustrated and described and details are given of the process of tapping and stopping up the hole.—J. C. R.

Open Hearth Charge and Feed Oxides. B. D. McCarthy. (Blast Furnace and Steel Plant, 1948, vol. 36, Dec., pp. 1475, 1512–1513). The physical and chemical requirements of iron ore for use in the open-hearth furnace, both in the charge and for decarburization are described. In each case a high iron content is essential; silica and phosphorus should be low, silica higher than 5% being tolerated in the decarburizing ore, but not in the charge ore. Ore for charging should be of a fairly high bulk density and free from moisture; a higher bulk density and a lumpy form are required in the decarburizing material. It is suggested that in view of the shortage of good high-grade iron ore in the U.S.A., compacted blocks of concentrated magnetite should be used. Tests have shown the suitability of these for both charging and decarburizing purposes: Their analysis includes: Iron 63·5–64·0%, silica 4·40–5·00%, lime 2·0%, sulphur 0·03%, phosphorus, 0·10%, and moisture 4·50%.—J. P. S.

Use of Oxygen for Steelmaking. A. G. Robiette. (Kjemi, Bergvesen og Metallurgi, 1948, vol. 8, No. 6, June: Chemical Digest, 1949, vol. 3, Mar., pp. 166–170). *See* Journ. I. and S.I., 1948, vol. 159, Aug., p. 436.

The Ionic Nature of Metallurgical Slags. Simple Oxide Systems. J. Chipman and L. C. Chang. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2529: Journal of Metals, 1949, vol. 1, Feb., Section 3, pp. 191–197). The authors have examined, in the light of ionic theory, recent data on slag–metal and slag–gas equilibria, with the purpose of obtaining a more complete and satisfactory generalization than has been possible on either of the single bases of simple compound formation or complete ionization. The theory of complete ionization of open-hearth slags is discussed and it is shown that ion activities may be useful without knowledge of the degree of ionization. Temkin's use of ion fraction as a measure of ion activity is a useful approximation; ionic solutions which are ideal in this respect may be achieved by judicious selection of ion formulæ. The data of Darken and Gurry on equilibria of gases with liquid iron oxides are consistent with the ion formulæ Fe^{++}, O^{--}, $Fe_2O_5^{4-}$ and Fe^{3+}, the last being significant only in highly oxidized slags. Thermodynamic relationships among these ions are deduced from the data. Data on the distribution of iron oxide between metal and simple oxide slags are shown to be consistent with the same iron formulæ and thermodynamic constants. In iron oxide slags the ion activity coefficients are unity. Addition of CaO or MgO has little effect on the activity of oxide ion but causes a sharp decrease in activity coefficient of $Fe_2O_5^{4-}$ ion. The differences in basic strength of oxides in slags are ascribed to differences in the abilities of the cations to form inactive complexes with the larger anions such as $Fe_2O_5^{4-}$ and SiO_4^{4-}.

Relation between Chromium and Carbon in Chromium Steel Refining. D. C. Hilty. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2507: Journal of Metals, 1949, vol. 1, Feb., Section 3, pp. 91–95). In this laboratory investigation undertaken to establish the fundamental carbon–chromium relationship in molten iron under oxidizing conditions, Armco iron and low- and high-carbon chromium metal were charged to produce heats of from 0·06% to 0·40% of carbon and 8% to 30% of chromium. Oxygen was injected at intervals and samples taken between the injections, the temperature being maintained constant between 1750° and 1820° C. Data obtained are presented and the following conclusions are drawn: (1) At constant temperature the relation between carbon and chromium in chromium steel can be expressed by the equilibrium constant,

$$K = \frac{\%\ \mathrm{Cr}}{\%\ \mathrm{C}}$$

(2) The probable reaction is believed to be:

$$CrO_{(sat.)} + C = Cr + CO_{(g)}$$

where the carbon and chromium are the amounts dissolved in the iron. (3) The effect of temperature on the relation has been derived and may be defined by the equation:

$$\mathrm{Log}\ K = -\frac{15{,}200}{T} + 9{\cdot}46$$

The Interaction of Liquid Steel with Ladle Refractories. C. B. Post and G. V. Luerssen. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2496: Journal of Metals, 1949, vol. 1, Jan., Section 3, pp. 15–26). Data are presented to show the effect of manganese and silicon contents of basic electric-arc melted steel on the resulting cleanness as measured by the Magnaflux test. The steels used for these investigations were SAE 6150, SAE 3312, AMS 6260 and a 1% carbon, high-manganese, high-silicon roller-bearing grade of steel. A high manganese content with a low silicon content led to more non-metallic inclusions than were present when manganese and silicon contents were substantially equal. Experimental data showed that the manganese and silicon contents of liquid steel, as expressed by the manganese to silicon ratio, did in fact markedly affect the silica content of slag buttons collected from the sides of ingots. The chemical influence of liquid steel on the physical characteristics of the metal–brick interface is discussed and it is considered that the majority of non-metallic inclusions which are detected by the Magnaflux test have their genesis at the interface between liquid steel and ladle brick, and the nozzle.—J. C. R.

The Influence of Temperature on the Affinity of Sulphur for Copper, Manganese, and Iron. E. M. Cox, M. C. Bachelder, N. H. Nachtrieb and A. S. Skapski. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2505: Journal of Metals, 1949, vol. 1, Jan., Section 3, pp. 27–31). The equilibrium constants of the reactions of iron sulphide, manganese sulphide, and copper sulphide with hydrogen were measured within a range of temperature wide enough to establish their dependence on temperature. From these data the equilibrium pressures of sulphur over the respective sulphides and the free energy of formation of the sulphides were calculated. The affinity of sulphur for copper (as measured by the free energy of formation of the sulphide) is considerably greater than that for iron, and begins to exceed that for manganese at temperatures above 1350° C. It is concluded that metallic copper which is present in the scrap is to be expected to pick up sulphur from the open-hearth furnace gases and thus raise the sulphur content of the bath.—J. C. R.

FOUNDRY PRACTICE

Some Fundamental Problems in Foundry Planning. J. Drachmann. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A179–A189). *See* Journ. I. and S.I., 1948, vol. 160, Dec., p. 437.

Problems in a Quantity Production Foundry. J. Hird. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B90–B97). *See* Journ. I. and S.I., 1948, vol. 159, May, p. 88.

Foundry Production Control. W. A. Turner and A. K. Jeffrey. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B118–B133). *See* Journ. I. and S.I., 1948, vol. 160, Sept., p. 107.

The Metallurgist in the Foundry. W. H. Salmon. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B82–B89). *See* Journ. I. and S.I., 1948, vol. 159, May, p. 90.

The Constant-Charge System of Cupola Operation. W. W. Braidwood. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B67–B74). *See* Journ. I. and S.I., 1948, vol. 159, Aug., p. 437.

New Methods of Ladle De-Sulphurizing Pig Iron. W. C. Newell, A. J. Langner, and J. W. Parsons. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A166–A172). *See* Journ. I. and S.I., 1948, vol. 160, Nov., p. 323.

Gray Iron in the Jobbing Foundry. F. W. Kellam. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, Dec., pp. 20–22, 31). The production of grey iron and Ni-Hard and Ni-Resist cast irons at the foundry of William Kennedy and Sons, Ltd., Owen Sound, Ontario is described. The melting equipment consists of one 30-in. cupola, one 52-in. cupola, and one 2-ton electric furnace. Particulars of the charging practice, and melting and slag control are given. R. A. R.

Specialized Foundry Control for Composite Castings. A. K. Higgins. (Metal Progress, 1948, vol. 54, Nov., pp. 679–682). The author discusses problems that arise when producing small castings having prefabricated inserts included in their structure either for strengthening vital portions or for giving specialized properties to limited surface areas. Among the factors considered are: The materials to be used; surface preparation of the inserts; moulding practice; gating the mould; preparation of the melt for casting; and pouring temperature. It is claimed that foundry scrap can be kept below 0·2%.—J. C. R.

Nodular Cast Irons, Their Production and Properties. H. Morrogh and J. W. Grant. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A29–A53). *See* Journ. I. and S.I., 1948, vol. 160, Nov., p. 338.

Solved and Unsolved Problems in the Metallurgy of Blackheart Malleable. H. A. Schwartz. (Proceedings of the Institute of British Foundrymen, "Edward Williams" Lecture, 1947–48, vol. 51, pp. A21–A28). *See* Journ. I. and S.I., 1949, vol. 161, Jan., p. 75.

The Annealing of Whiteheart Malleable Iron in Controlled Atmospheres. J. Piaskowski. (Przeglad Mechaniczny, 1948, vol. 7, May, pp. 212–218).

High-Frequency Induction Heating—Application of the Theory to Melting Furnaces. M. Renouard. (Révue Générale Electrique, 1948, vol. 57, No. 8, pp. 322–337: American Ceramic Abstracts, 1949, Jan. 1, p. 23). Principles and theory are explained and the latter is applied to industrial melting furnaces without a magnetic core. This type of furnace is suitable only for metals and alloys of high resistivity; in other cases the efficiency becomes poor. An example is given.

Steel Castings for Aircraft. E. J. Brown and F. Rodgers. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A95–A106). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 222.

Steel Foundry Research. T. Bishop and K. G. Lewis. (Foundry Trade Journal, 1949, vol. 86, Feb. 10, pp. 111–117). This is an account of research work on steel foundry problems being undertaken by the British Iron and Steel Research Association. It includes discussions on improvements in the fluidity test, the effect of casting temperature upon the surface of a standard test casting made in a sand mould of set character, the types of reaction associated with burnt-on sand, and hot tearing. Brief notes are also given on the choice of moulding sands and investigations on bonding materials being carried out at Sheffield University by Dr. White.—J. C. R.

Steel Foundry Practice and Maintenance. F. J. Macano. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 818–824: Iron and Steel Engineer, 1948, vol. 25, Nov., pp. 98–104). Various methods of ramming moulds and cores are discussed and a note on sand reclamation is included.—J. C. R.

The Development of Foundry Sand Control. G. L. Harbach. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B22–B44). *See* Journ. I. and S.I., 1948, vol. 159, May, p. 89.

Olivine. Possible Alternative Material for Foundry Work. (Iron and Steel, 1949, vol. 22, Feb., p. 44). A brief account is given of the occurrence, properties, and applications of olivine. It is more refractory than quartz and shows greater resistance to scorification of iron oxides. It is used in the foundry as a substitute for silica sand and may be used as a dusting powder or, as an insulating material.—J. C. R.

Bonding Clays in the Foundry—I. L. Sanderson. (Practical Engineering, 1948, July 9, p. 656: British Ceramic Abstracts, 1948, Nov., p. 365A). The nature and properties of clays are generally and briefly discussed with special reference to the effect of moisture and green strength. Used as a bonding medium in moulding sands the clay must possess resistance to high temperatures, sufficient plasticity to ensure the use of a minimum quantity, good covering properties, capacity to retain moisture and a long service life with ability to be reused. Lack of two or more of these requirements can cause failure of the moulding sand and consequent defects in the castings. Of the twelve factors which influence the behaviour of a moulding sand, of which nine are governed to some extent by the clay, the four main ones are strength and moisture content, ability to flow, permeability, and service life and durability. The following table shows that, by careful control of clay and water content, heavier rammings can be given to develop the strength required:

No. of rammings	¼	½	1	2	3	9	18
Hardness	0	41	65	78	82	92	95
Green compression strength (lb./sq. in.)	1·2	1·9	3·3	5·3	6·8	14·1	26·0

Powdered Graphite in Foundry Practice. P. Nicolas. (Fonderie, 1948, Oct., pp. 1354–1356: Foundry Trade Journal, 1949, vol. 86, Feb. 24, pp. 160–161). Details are given of X-ray examination, sieve tests and foundry tests of Italian, Madagascan and Moroccan graphite, with their chemical compositions. Italian graphite had the finest structure and gave the best results for the compounding of dressings used for coating chills, dies, or stoved work. Madagascan graphite was preferred as a parting powder for green-sand moulds as the coarser structure responded better to the smoothing and rapping conditions involved.—J. C. R.

Porosity-Free Castings from Permanent Moulds. H. Kalpers. (Archiv für Metallkunde, 1948, vol. 2, No. 9, pp. 318–320). Permanent moulds of ceramic material are recommended as a method of producing castings free from porosity because the mould resists the pressure of the liquid metal better than sand and is more porous, thus facilitating the rapid escape of gas. No risers are required. Examples are described which include the casting of 34 machine bedplates from one mould. The process is attributed to W. Büsselmann. Technical details of the ceramic material are not given.—R. A. R.

Dry-Sand Patterns. J. Timbrell, sen. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B54–B58). *See* Journ. I and S.I., 1948, vol. 159, Aug., p. 437.

Cores, Core-Making and Core-Making Materials. J. G. Gilbert. (Institute of British Foundrymen: Foundry Trade Journal, 1949, vol. 86, Feb. 24, pp. 133–137; Feb. 24, pp. 155–158). The author discusses the different types of oil sand, their properties, and the technique of mixing them. An account is given of the making of oil-sand cores, including the use of cast-iron grids and other tackle, and methods of venting. The second part of the paper deals with core drying, core washes, and the advantages of jigging or fixing together as many cores as possible.—J. C. R.

Venting of Cores and Moulds. D. Killingworth. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B98–B103). *See* Journ. I. and S.I., 1948, vol. 159, July, p. 331.

The Loam Moulding of Rope-Barrel Castings. D. Robertson. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B45–B53). *See* Journ. I. and S.I., 1948, vol. 159, Aug., p. 437.

The Manufacture of Some Large Castings for Marine Engineering. D. H. Young. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B8–B17). *See* Journ. I. and S.I., 1948, vol. 159, May, p. 89.

Practical Aspects of Machine Moulding. J. H. Peers. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. B18–B21). *See* Journ. I. and S.I., 1948, vol. 160, Sept., p. 106.

Deviations of Chemical Composition at the Surface of Cast Iron from the Average Composition and the Causes of This, Particularly the Effect of the Moulding Sand. E. Diepschlag and F. Grosser. (Metalloberfläche, 1949, vol. 3, Jan., pp. 1–8). Test bars of iron with different silicon contents (1·43% and 2·31%) but of otherwise similar composition were cast in two sands which differed considerably in grain-size and permeability but not in the slimes fraction; determinations were then made of total carbon, silicon, manganese, phosphorus, and sulphur in samples from the core and the surface. The skin of the casting is not homogeneous and its silicon content is greater than that of the core. The carbon, manganese, and phosphorus contents are less at the core than at the surface. The changes in composition do not occur in a single phase but in a heterogeneous system. The oxidation of the carbon occurs between gas and liquid phases,

whilst the manganese and phosphorus reactions take place between two liquid phases. Precipitation of carbon is possible only when an oxidizing gas phase is present, and there is more oxidation with increasing permeability of the sand. The sulphur is oxidized to sulphur dioxide at the surface and the sulphur content is therefore less at the surface, the decrease being the greater with greater permeability of the sand. R. A. R.

Application of the Brinell Test in the Foundry. J. Léonard. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A211–A216). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 222.

Problems of Contraction and Distortion in Cast-Iron Castings. E. Longden. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A152–A165). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 222.

The Cleaning of Steel Castings. A. B. Lloyd. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A107–A122). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 222.

Shrinkage Cavities. Their Elimination by the Quasi-Bessemerizing Process. W. S. Williams. (Iron and Steel, 1949, vol. 22, Feb., p. 55). Previous reference has been made to the Quasi-Bessemerizing process (*see* Journ. I. and S.I., 1943, No. I, p. 80A and 1945, No. I, p. 98A). In this article the author describes its application in the elimination of shrinkage cavities. One result of the use of this process is that low-silicon iron with pronounced shrinkage characteristics can be used in the manufacture of ingot moulds without fear of the formation of shrinkage cavities.—J. C. R.

Costing in the Iron Foundry. T. Lee. (Engineer and Foundryman, 1948, vol. 13, Oct., pp. 37, 39, 59).

HEATING FURNACES AND SOAKING PITS

Heating of Objects in Furnaces. V. Vondraš. (Strojnický Obzor, 1947, vol. 27, June, pp. 245–250, July, pp. 280–282). [In Czech]. The process of heating solid objects of various shapes in furnaces is mathematically analysed. General solution of the basic differential equations defining the temperature characteristics throughout the cross-section of the heated object is a lengthy process and for practical purposes it is sufficient to determine the temperatures on the surfaces and at the centre of the heated object.

These temperatures can be calculated by means of simplified equations or graphs. For a furnace of constant temperature the temperatures on the surface and at the centre t_m of the heated object, and also its mean temperature can be expressed by an exponential function, *e.g.*,

$$t_m\,(°C.) = t_f - (t_f - t_0)[\rho - (\rho - 1)\kappa]e^{-\frac{\alpha\,\kappa}{X\,\gamma\,c}\tau}$$

where t_f and t_0 are the temperature of the furnace and the initial temperature of the object respectively; the values for κ are obtained from curves which are presented, and $\rho = 1{\cdot}5$, $2{\cdot}0$, and $2{\cdot}5$, depending on the shape of the object, α is the coefficient of heat transfer from furnace atmosphere to surface of object, γ is the specific gravity of the object, c is its specific heat, and X is its volume divided by the surface area. The time required to heat a part to a required temperature can be calculated by the equation:

$$\tau\ (\text{hours}) = \frac{X\,\gamma\,c}{\alpha\,\kappa}\ \log\ \frac{t_f - t_0}{t_f - t}$$

where t is the final temperature of the object. Equations are also given for furnaces with a constant heat input. For materials where the specific heat and the coefficient of heat transfer vary with the temperature, the calculation is made in several temperature ranges and in each range these values are assumed to be constant. Heating with a constant supply of heat has the disadvantage that, throughout the process, the difference between the temperatures of furnace and part is always considerable, thus causing internal stresses. With steel it is best to increase the heat input gradually, attaining a maximum input at the highest temperature of the part and to decrease the input gradually towards the end of the holding time. Sufficient time must be allowed to permit the part to be heated right through. The furnace temperature should not greatly exceed the desired temperature of the part, as this causes the temperature of the core to be too low when the surface reaches the desired temperature. According to Trinks 160 kg. of steel/hr./sq. m. can be heated to the hardening temperature in a gas furnace and 315 kg. to the annealing temperature. In an electric furnace with an input of 30 kW./sq. m. 280 kg. can be heated per hour to 1000° C. The time for heating in a gas-fired muffle furnace from 20° to 400–1200° C. is given by

$$\tau\ (\text{min}) = 500\,\frac{D - 10}{t - 200}$$

where D is the diameter (mm.) of the heated bar and t is the final temperature which is approximately equal to the furnace temperature. In a lead bath the time for heating from 200° to 500–900° C. is

$$\tau\ (\text{min}) = 0{\cdot}114D + 0{\cdot}00008Dt.$$

In a salt bath the time for heating from 400° to 550–750° C. is given by

$$\tau\ (\text{min}) = 110\,[D/(t - 200)].$$

In a salt bath fitted with electrodes the time for heating from 850° to 1000–1300° C. is

$$\tau\ (\text{min}) = 0{\cdot}05D - 0{\cdot}00013(D - 15)t.$$

In an oil bath the time from 20° to 120–260° C. is

$$\tau\ (\text{min}) = 290(D - 20)/(t - 100).$$

Data are also presented for larger objects and for the holding times at various desired temperatures.—E. G.

Temperature Distribution in Furnace Walls of Varying Thermal Properties. A. J. Thompson. (Gas, 1948, vol. 24, Mar., pp. 48–49: [Abstract] British Abstracts, B.I, 1948, Oct., col. 511). Some aspects of heat transfer in the design of high-temperature furnaces are discussed, and results obtained from the operation of typical insulated and non-insulated furnaces compared.

Industrial Gas Installations. (British Intelligence Objectives Sub-Committee, 1949, Final Report No. 1800: H.M. Stationery Office). This comprehensive report on industrial gas installations in Germany covers visits to 23 works nearly all of which are connected with the production or finishing of steel. Some technical reports are included which cover space heaters, the flow of gas through valves and its controllability, heating salt baths, heat calculations relating to galvanizing kettles, a comparison of the heat losses of two furnaces (one of firebrick and one of light-weight refractories) which showed the advantages of the latter, and testing industrial burners.—R. A. R.

FORGING, STAMPING, DRAWING, AND PRESSING

How Forging Acts to Enhance Metal Properties. E. O. Dixon and E. J. Foley. (Transactions of the American Society of Mechanical Engineers, 1949, vol. 71, Feb., pp. 147–152). This investigation was undertaken to study the effect of reduction and of forging method upon the mechanical properties of steel. Neither amount of reduction nor method of forging altered the strength properties at a given hardness level with regard to direction of grain flow. A successive series of experiments on steel treated to varying ranges of strength showed superior transverse ductility and notched-bar toughness developed by the extremely high pressure used in closed-die forging. Tests, in which the amount of plastic deformation was negligible, demonstrated that pressure alone in closed-die forging effected an improvement in transverse ductility.—J. C. R.

New Machine Eliminates Stainless Flange Welds. H. Frankfort. (Chemical Industries, 1948, vol. 62, pp. 752–753: British Abstracts, B.I, 1948, Nov., col. 638). Thin-walled, stainless-steel tubing is cold "vanstoned" in the field by means of a hydraulically operated machine which rolls the end of the tube to the required form. Tubing and fittings are assembled by means of carbon steel, split-type, back-up flanges. The fire hazards attached to welding work on site are eliminated and the pipelines are easily dismantled. Comparative weights and costs are discussed.

The Design of Press Dies for Extrusion Presses. F. Hemmerich and N. Arenz. (Metallwirtschaft, 1949, Feb., pp. 37–40). Factors affecting the design of dies for extrusion presses are discussed.—R. A. R.

Contribution to the Knowledge on Drawing Chromium-Bearing Steels into Wires. W. Bischof and W. Püngel. (Verein deutscher Eisenhüttenleute, 1943, Confidential Report No. 49). An investigation of the causes of the bad drawing properties of some steel wires containing up to 0·36% of chromium is reported. It appears to be the form

in which the chromium is present which is important. High-frequency furnace steel with up to 0·36% of chromium, added as ferrochromium, did not have the poor drawing properties which similar open-hearth furnace steel had. When the chromium is below 0·10% its effect is very slight. Increasing the chromium shifts the temperature–time curve for the isothermal transformation of austenite towards longer immersion times so that longer times for patenting are required. Good drawing properties are obtained when the wire has fairly coarse grains which can be deformed 80% in the cold state ; this is only possible with thin wire.—R. A. R.

The Wire Drawing Die. K. B. Lewis. (Wire and Wire Products, 1949, vol. 24, Jan., pp. 67–71, 105, 106). The history of the development of the wire-drawing die is outlined, special reference being made to developments in the U.S.A. since 1926.—R. A. R.

The Development of Wire-Drawing Lubricants during the War. W. Heidenhain. (Verein deutscher Eisenhüttenleute, 1944, Confidential Report No. 80). This report gives an account of the efforts made in Germany before and during the 1939–45 war to produce wire-drawing lubricants which did not contain sodium soaps. They succeeded in preparing mixtures of mineral oils and synthetic fatty acids which answered the purpose.—R. A. R.

A New Theory of the Plastic Deformation in Wire-Drawing. R. Hill and S. J. Tupper. (Wire Industry, 1948, vol. 15, Nov., pp. 739–741 ; Dec., pp. 811–813). *See* Journ. I. and S.I., 1948, vol. 159, Aug., pp. 353–359.

ROLLING-MILL PRACTICE

Electric Motors Over Three Hundred Horsepower. (Iron and Steel Engineer, 1949, vol. 26, Jan., pp. 118–119). Details are given of electric motors of over 300 h.p. applied to main roll drives in the iron and steel and allied industries during 1948.—J. C. R.

Electrical Drive Equipment for New High Speed Tandem Mill. A. F. Kenyon. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 807–817 : Iron and Steel Engineer, 1948, vol. 25, Nov., pp. 49–59). A detailed and illustrated account is given of the electrical drive equipment for the new 42-in. five-stand tandem cold reduction tinplate mill at the works of the Weirton Steel Co. which operates at speeds up to 5000 ft. per min.—J. C. R.

Eliminating Defects Through Improved Rolling Methods. J. A. Tischbein. (Iron and Steel Engineer, 1949, vol. 26, Jan., pp. 57–65). The author analyses methods and improvements that have helped to eliminate injurious seams and surface defects that are common to a 14-in. bar mill or mills of similar design. Roll pass design and procedure are discussed with reference to the advantages of diamond and square reduction over oval and square reduction. Other factors considered are the use of guides in a rolling mill, the proper preparation and rolling of the billets, and reheating of the blooms to obtain a good surface on the finished product. J. C. R.

New Cold Mill at Weirton Increases Tin Plate Capacity. C. J. Klein. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 795–806 : Iron and Steel Engineer, 1948, vol. 25, Nov., pp. 37–48). After briefly outlining the processes involved in the production of black plate, the author describes the development of the manufacture of tinplate at the works of the Weirton Steel Company. The new 42-in. five-stand tandem cold strip mill operates at a speed up to 5000 ft. per min., and has a capacity for rolling 45,000 tons/month. The product of the mill is primarily tin mill coils in gauges from 38 (0·0060) in. to 29 (0·0135 in.), and in widths up to 38 in., and also sheet mill coils in gauges up to 0·025 in. thick and in widths up to 38 in. Details of the charging and coiling equipment, roll stands, mill drives, and lubrication systems at the works, are given.—J. C. R.

MACHINERY FOR IRON AND STEEL PLANT

Steam for Chile's New Steel Plant. F. C. Senior. (Combustion, 1948, vol. 19, Apr., pp. 32–34 : Fuel Abstracts, 1948, vol. 4, Nov., p. 128). Compania de Acero del Pacifico in collaboration with Kopper Co., Pittsburgh is now constructing a complete integrated steelplant in Chile. It will be the second largest in South America, with initial installed capacity of approximately 250,000 tons of ingots per year. Its boiler plant will contain two 70,000 lb. per hour steam generating units designed for burning coke breeze and blast-furnace gas or coke-oven gas. A waste-heat boiler will generate steam by waste heat from the open-hearth furnace. Normally, electricity will be supplied over a 90-mile transmission line from a hydro plant, but a 2500-kW. condensing turbine-generator at the plant will provide standby power.

Steel Plant Communications. W. P. Place. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 850–854 : Iron and Steel Engineer, 1948, vol. 25, Nov., pp. 94–97). The author describes developments in the equipment used for facilitating communication in steelplants.—J. C. R.

Steel Mill Power Generation, Transmission and Distribution. D. L. Beeman. (Iron and Steel Engineer, 1949, vol. 26, Jan., pp. 66–74). Various problems connected with the design of power generation conversion and distribution systems in American steelworks are discussed.

Grinding Steel Billets at SKF Hofors. (Ball Bearing Journal, 1948, No. 2, pp. 22–27). Illustrated descriptions are given of the grinding machinery for removing surface defects from steel billets at the SKF (Swedish Ball-Bearing Works) plant at Hofors. Swing grinders are employed with 16 in. × 2 in. grinding wheels belt-driven by a 10-h.p. motor to run at 3880, 3160, or 2760 r.p.m.—R. A. R.

WELDING AND FLAME-CUTTING

Influence of Metallurgical Factors on Welding. J. Dittl. (Svařování, 1948, vol. 8, No. 9, pp. 117–127). [In Czech]. The paper describes the influence of various gases, particularly that of oxygen, nitrogen, and hydrogen, on the quality of welds. Oxygen is particularly harmful if its contents increase above 0·1% when it affects the notch toughness of the material, and the structure gets coarser. The influence of up to 0·20% each of oxygen and nitrogen on the mechanical properties of steel is shown by graphs. The author outlines briefly the known protective effects of the various types of coating, with special reference to electrodes produced in Czechoslovakia. The occurrence of 'fish eyes' in welds produced by high quality electrodes is explained and methods for their elimination are described. The author outlines briefly the temperature distribution during welding and the changes of structure which occur during cooling. The utility of the Jominy and slow notch bend tests for the determination of welding current, welding speed, and choice of suitable electrodes is demonstrated by a practical example. The isothermal time–temperature transformation diagram is also explained and it is shown how it can be used in the selection of suitable electrodes and heat-treatments for repairing dies and tools by welding.—E. G.

Crystalline Fracture in Welded Structures and Transition Temperature of Steels. F. Bustelo. (Revista de Ciencia Aplicada, 1948, vol. 2, pp. 81–86 : British Abstracts, B.I, 1948, Dec., col. 718). The nature of crystal fracture in welded structures and the various factors concerned, *e.g.*, temperature, rate of deformation, and multi-axial forces, are discussed together with the tests involved, such as the notched-bar test at very low temperatures, for determining the critical value of stresses produced. The transition temperature at which there is an abrupt fall in absorbed energy is of special interest ; this is shown in a graph. There may be wide dispersion in results, requiring adjustment of the curve, and the transition temperature may vary within wide limits, from − 60° to + 80°. Reference is made to the notched-bar tests of Graf, Izod, and Charpy.

The Problem of Cracking and Fractures Associated with Arc Welded Steel Work. A. E. Berriman. (New Zealand Engineering, 1948, vol. 3, Nov. 10, pp. 1093–1098). The mechanism of the cracking of welded joints in steel, especially high-tensile steel, and the Reeve cracking test, are described. Ball's diagram for rapidly determining the dimensions of the first runs when making butt welds in ½-in. and 1-in. steel plates, and the Dearden O'Neill formula for calculating the carbon equivalent and predicting the hardness of welds in alloy steels are presented. Finally, the hardness of oxy-actylene cut edges is discussed ; no special measures need be taken if these edges are to be welded.—R. A. R.

Residual Stresses Due to Welding. R. Weck. (Welding Journal, 1949, vol. 28, Jan., pp. 9-s–14-s). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 645.

Notch Sensitivity of Welded Steel Plate. R. D. Stout and L. J. McGeady. (Welding Journal, 1949, vol. 28, Jan., pp. 1-s–8-s). This is a continuation of previous work (*see* Journ. I. and S.I., 1947, vol. 157, p. 300 ; 1948, vol. 158,

p. 408; 1948, vol. 160, p. 444) by the authors and various colleagues. The longitudinal notched bend test was employed, and the evidence of cracking studied. It was found to begin at low angles of bend in both prime and welded plate. Where the steel is of about 0·18% carbon content and contains no alloying elements, the first crack appears in the weld metal, but in steels of higher carbon or alloy contents it appears in the heated zone of the plate metal. Normalizing lowers the fracture transition temperature of both prime and welded plate, and the ductility transition temperature slightly in the unwelded, and noticeably in the welded, plate. The longitudinal notch bend test indicates the effect on such transition temperatures of composition, plate thickness, welding, heat-treatment, and strain-ageing. The relative significance of ductility measurements and observations of the type of fracture may be explained by examination of satisfactory and unsatisfactory plates in service.—J. P. S.

The Metallurgy of Covered Electrode Weld Metal. G. E. Claussen. (Welding Journal, 1949, vol. 28, Jan., pp. 12–24). Experiments directed towards discovering the part played by slags in the welding operation have consisted of analysing both slag and weld metal and studying the distribution of various elements between them. The following conclusions relating only to the coatings and electrodes under test (where the electrodes were $\frac{5}{32}$-in. rods containing 0·13% C, 0·43% Mn, 0·012% P, 0·023% S, trace Si, and the coatings were various mixtures of iron and manganese oxides, silica, titania, calcium fluoride, lime, organic binders, etc.) were drawn: (1) The sulphur distribution was near equilibrium, dependent on the slag basicity, the oxides of calcium, manganese, magnesium and sodium acting as bases, while titania appeared to act as an acid constituent; (2) the phosphorus distribution did not reach equilibrium, a higher proportion than that for equilibrium being transferred to the weld metal: and (3) the reactions in the slag between iron oxide and silicon and manganese were the most important ones in determining the distribution of these elements. The reactions appeared to reach equilibrium; in three of the coatings enough manganese, as metal, had been added to provide a slag in equilibrium with weld metal containing 0·25–0·45% of manganese. The author warns readers that no account has been taken of water in the coatings and that its effect is important.—J. P. S.

Electrodes and Metals. A. S. Tuttle. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, Dec., pp. 25, 29–31). The development of welding electrodes, their standardization and nomenclature is discussed.—R. A. R.

CLEANING AND PICKLING

Degreasers. F. V. Faulhaber. (Products Finishing, 1949, vol. 13, Jan., pp. 26–36). Degreasing equipment using trichlorethylene-base solvents is described and the design, selection, installation, and operation of the units are discussed. R. A. R.

Pickling Prior to Hot Galvanizing. A. Gordet. (Métallurgie, 1949, vol. 81, Jan., p. 27; Feb., p. 27). Various factors which affect the period and effectiveness of the pickling process prior to hot galvanizing are discussed. These include the nature of the acid, the concentration and temperature of the bath, and the nature and use of inhibitors.—J. C. R.

Dry Lime Treatment of Waste Pickle Liquor. C. J. Lewis. (Iron Age, 1949, vol. 163, Jan. 20, pp. 48–53). Waste pickle liquors are usually neutralized with lime slurry and de-watered by "lagooning." To save space in congested surroundings, de-watering by vacuum filter or centrifuge may be used, but the sludge formed by the use of lime slurries is not easy to treat by these means. If dry lime is employed for neutralizing, a granular precipitate is formed which may be removed in this manner. A pilot plant is described. The liquor is neutralized in an agitated tank, settled, and the supernatant liquor drawn off and run through filter presses. The sludge is pumped by a positive displacement pump, either to a vacuum filter or to a centrifuge; the effluent from these may be run through the same filter presses if it is not clear enough for discharge to streams or rivers. The conditions arising with varying acid contents of the pickle liquor, and in the presence of grease in the liquor are considered, and the larger scale application of the process is studied.—J. P. S.

New Technique for Waste Pickle Liquor Neutralization. R. D. Hoak and C. J. Sindlinger. (Industrial and Engineering Chemistry, 1949, vol. 41, Jan., pp. 65–70). When waste pickling liquors are neutralized with lime there is the difficulty, as well as the expense, of dealing with large quantities of sludge. This paper describes a new technique whereby a substantial reduction in the volume of sludge is effected, settling is completed in less than 1 hr., and the vacuum filtration rate is increased markedly. The tests described were run in a reactor consisting of a tube $8\frac{1}{2}$ in. dia. × 30 in. high in which a shaft carrying three impellers 6 in. apart was rotated by a motor; air was supplied to each impeller by separate tubes, and waste pickle liquor was admitted by a tube below the lowest impeller. A vertical baffle furnished the necessary turbulence. For each run, the alkaline agent (magnesia, high-calcium lime, or dolomitic lime) was slaked in water and well mixed with about 8 litres of slurry left in the reactor from a previous run. The mixture was heated and the air feeds to the impellers set at the desired rate; the pickle liquor was fed at a constant rate until 8 litres had been added. A sample of slurry was then filtered and the filtrate tested for soluble iron, if iron was present, the air feed was continued until the iron oxidized and was precipitated. Successful operation depends primarily on balancing the rate of iron precipitation with the rate of oxidation of ferrous hydrate. These rates must be controlled to produce a ferric to ferrous iron ratio in the precipitate of between 2 and 5 (preferably 2·5 to 3·5), while the temperature of the bath is maintained high enough to promote the formation of ferrosoferric oxide. There are two reasons for the high filtering rates of the slurries made by this process: (1) The iron is precipitated as a finely divided, non-gelatinous, hydrated ferrosoferric oxide; and (2) the coprecipitated calcium sulphate is distributed through the slurry as needle-shaped crystals which assist the filtration.—R. A. R.

Diphase Metal Cleaners. I. Reich and F. D. Snell. (Industrial and Engineering Chemistry, 1948, vol. 40, Dec., pp. 2333–2337). A comparison is made between unstable and stable emulsion-type solutions for cleaning metals. Cleaning tests were performed on steel washers soiled by coating with a paste of umber in oil. Diphase cleaners were more effective than stable emulsion cleaners because of their ability not only to wet and detach the paste from the surface, but also to disperse and suspend the oil, thus preventing redeposition.

Rust Removal and Metal Conditioning. J. Bockman. (Organic Finishing, 1946, vol. 7, No. 2, pp. 15–22, 35: Chemical Abstracts, 1949, vol. 43, Jan 10, col. 100). Rust and scale can be removed in various ways with varying degrees of effectiveness. Various chemical methods have been and are being used for rust and scale removal. Sulphuric and hydrochloric acids are used and, while they do accomplish this purpose, their use is sometimes objectionable. Parts are not allowed to dry between the rust-removal tank and the first water rinse. A fresh cold-water spray hits the parts between these two stages, removing the excess rust remover and metal conditioner. The parts then pass into a final rinse which consists of $\frac{1}{16}$ of 1% CrO_3 chips by weight, the balance being water. This is the equivalent of 8 oz. CrO_3 chips to 100 gal. water. This rinse is maintained at a temperature of 180° to 190° F. The parts pass through for a period of 90 sec. After immersion they pass over a small stream of the last rinse liquid which flushes out the cavity and threaded area. After this, parts pass over a series of air jets for quick drying. The rust remover and metal conditioner solution removes all rust and conditions all areas for good paint adhesion. The residue left from this operation consists of a grey-white iron phosphate that insures paint performance under adverse atmospheric conditions.

Electropolishing of Stainless Steel on an Industrial Scale. J. J. Dale and C. E. Naylor. (Defence Research Laboratories (Australia) 1948, Circular 11: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 413). The orthophosphoric sulphuric acid process (Faust and Pray) and the orthophosphoric acid glycerine process (Uhlig) have been tried out, and concise useful practical operating details are given, including a variant of the Uhlig process recommended for the polishing of cutlery-type stainless steels.

Surface Finishing of Stainless Steels. K. M. Huston. (Plating, 1948, vol. 35, Nov., pp. 1106–1110, 1142). Methods of surface-finishing stainless steels are reviewed with brief descriptions of the removal of scale by shot-blasting, tumbling, and pickling; cleaning with solvents, soaps, or steel wool; grinding, polishing, and bushing; electropolishing; and colouring and plating.

De-Enamelling by Caustic Soda. (Foundry Trade Journal, 1949, vol. 86, Jan. 13, pp. 33–34). An illustrated description is given of de-enamelling practice at the Winnington works of Imperial Chemical Industries, Ltd. where molten caustic soda is used as the bath. Immediately on immersion the thermal shock causes much of the enamel to flake off; thereafter solution of the enamel takes place rapidly, leaving only a fine coating of sludge adhering to the part. After 3 to 5 min. the parts are hoisted out of the bath, allowed to drain, racked well away from the bath, cooled, washed by hose pipes, and then immersed in nearly boiling water so that they dry rapidly. They are then ready for pickling and re-enamelling. The sludge is collected and can be utilized for neutralizing acid effluents.—J. C. R.

PROTECTIVE COATINGS

Plating. W. Engelhardt. (Die Technik, 1948, vol. 3, Sept., pp. 381–386; Nov., pp. 473–477). The conditions governing the strength and properties of the bond obtainable between two metals are discussed from both the theoretical and practical points of view, and several series of test results are given relating to copper bonded to various metals. A disc of copper 1 mm. thick was pressed between the machined and cleaned ends of round bars of the second metal in a protective atmosphere in a furnace and tensile tests were made on them after bonding at various temperatures, under different pressures and for different durations of pressure. At a pressure of 3 kg./sq. mm. there was no bond below 860° C. The strength of the bond increased slowly with temperature from 860° to 920° C., and then rapidly from 920° to 1000° C. The time at pressure had no effect on the bond strength in the range 1 sec. to 2 hr. The bond between steel and copper was more difficult to produce as the carbon content of the steel increased. The greatest strength at all bonding temperatures was obtained when both steel and copper were hardened before pressing together.—R. A. R.

Effect of Impurities and Purification of Electroplating Solutions. (Plating, 1948, vol. 35, Nov., pp. 1122–1123). Tests were made with three nickel-plating solutions (Watts bath, cobalt–nickel bath, and organic type bath) to determine the effect of copper in the solution on the salt-spray resistance of the coating. In all cases the resistance decreased with increasing amounts of copper in the solution.—R. A. R.

Electric Theory of Adhesion of Films to Solid Surfaces. B. V. Deryagin and N. A. Krotova. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 61, Aug. 11, pp. 849–852 [in Russian]: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 397). Theory ascribes a large part of the work of detachment of a film from a solid to the necessity of overcoming electrostatic attraction. Some measurements on adhesion of rubber to zinc, nickel, and steel are made.

Demonstration and Discussion of Apparatus for Evaluation of Adherence. A. C. Francisco. (Proceedings of the Porcelain Enamel Institute Forum, 1947, 9th Forum, pp. 25–27: American Ceramic Abstracts, 1948, Nov. 1, p. 239).

Shear Tests of the Adhesion of Electrodeposited Chromium to Steel. E. Zmihorski. (Journal of the Electrodepositors' Technical Society, 1948, vol. 23, pp. 203–213). A report is given of an investigation to determine quantitatively the adhesion of chromium deposits and the effect of certain variables on this property. A shear type of adhesion test was used and the effect of the following variables was investigated: Type of etching treatment used in preparation for plating, thickness of chromium deposit, composition of plating solution and current density, hardness of basis metal, effect of heat-treatment, and effect of rolling fatigue. Chromium–tungsten steel (C 1·1%, Mn 1%, Cr 1·2%, W 1·5%) which had been hardened and tempered to 620 Brinell, then ground, was used for the test-pieces. The results of the tests are presented.—J. C. R.

Measurement of Chromium Plating Thickness. C. H. R. Gentry and D. Newson. (Electroplating, 1948, vol. 1, Dec., pp. 759–765). A method is given for measuring the thickness of chromium plating by controlled electrolysis in dilute sulphuric acid. For laboratory operation an apparatus is described which records the thickness on a dial, whilst for use in the plating shops another apparatus has been constructed which automatically indicates whether the plating thickness is below or at the required thickness.—J. C. R.

Practical Points on Chromium Plating. R. L. Buckley. (Electroplating, 1948, vol. 1, Oct., pp. 626–628). The practical aspects of chromium plating are briefly reviewed.—J. C. R.

Chromium Diffusion into the Surface of Steel. (Technische Rundschau (Switzerland), 1948, Dec. 24: Iron and Coal Trades Review, 1949, vol. 158, Jan. 14, p. 76). An account is given of the "Inkrom" or "BDS" process in which chromium is introduced in the surface layers of a steel by diffusion. A laboratory method is first described in which a stream of hydrogen and hydrogen chloride was passed over red-hot ferrochrome, producing a chromium-chloride compound. When this compound was made to act at 1000° C. on the steel surface the chromium chloride was transformed into metallic chromium and iron chloride. A diffusion zone of 0·1–0·5 mm. was built up with 30% chromium at the surface. For commercial purposes a ceramic body was developed which could be charged with chromium chloride to provide an active substance for repeated use in the diffusion process. Steel specimens are packed in these active ceramic forms and heated in a furnace. High carbon steels give unfavourable diffusion zones. "IK" steels (mild unalloyed steels with tensile strengths of 20–30 tons/sq. in.) have been developed for use with this process. Treated surfaces are resistant to scaling up to 850° C. for long periods and at higher temperatures for shorter periods.—J. C. R.

Mist Control with Addition Agents in Chrome Plating. L. Silverman and R. M. Thomson. (Journal of Industrial Hygiene and Toxicology, 1948, vol. 30, Sept., pp. 303–306: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 396). Agents which lower the surface tension of chromium-plating baths are effective in reducing mist evolution. The authors consider, however, that in addition, some ventilation should be maintained if foam accumulates on the bath surface.

Chromium Plating in Maintenance Practice. R. M. Wick. (Iron and Steel Engineer, 1948, vol. 25, Dec., pp. 54–60). An account is given of the use of chromium plating in steelworks to prolong the life of tools and engineering parts, which are subject to considerable wear. The author outlines a rapid method of chromium plating such parts using a chromic acid plating bath containing a high concentration of sulphate radical in conjunction with a high temperature. A chromium plate of greatly improved quality is obtained for mechanical use, especially because of its resistance to impact.—J. C. R.

Modern Heat Applications in Galvanizing. W. O. Owen. (Steel Processing, 1948, vol. 34, Dec., pp. 659–662). The heating of galvanizing kettles by direct firing, convection, and radiant tubes is discussed with data on heat requirements and heat losses. Details are given of a method in which two rows of downward-pointing burners, one on each side of the kettle, project flames on to a bed of refractory material lying between the brick setting and the kettle walls.

The present trend is to relieve the kettle of heating load by bringing the parts to be galvanized up to temperature in a flux bath of zinc and ammonium chlorides, and to use a separate melting pot to melt the zinc to replace that taken out of the bath by the work.—R. A. R.

Working Instructions for Anti-Rust and Anti-Staining Treatment of Tinplate (The 'Protecta-Tin' Process). (Tin Research Institute, 1948, Mar., Pamphlet). The procedure for applying the 'Protecta-tin' process is described. After cleaning the tinplate to be protected, it is immersed for 30 sec. in a solution of trisodium phosphate, sodium dichromate, caustic soda, and a wetting agent, in soft water; it is rinsed in hot water and dried.—R. A. R.

J & L Rolls Tinplate at 70 Miles per Hour. (Iron and Steel Engineer, 1948, vol. 25, Feb., pp. 98A–101A). **Jones and Laughlin Improves Facilities for the Manufacture of Tin Plate.** (Blast Furnace and Steel Plant, 1948, vol. 36, Mar., pp. 317–321). Details are given of new equipment installed and projected at the Aliquippa and Pittsburgh works of the Jones and Laughlin Steel Corporation for the production, conveyance, and continuous pickling of hot-rolled cold-reduced tinplate.—J. R.

Solder Flow Tester for Tinplate. J. J. Speretto. (American Society for Metals, Oct. 1948, Preprint No. 43). An account is given of a simple rapid method for comparing the flow of soft solders; it is particularly suitable for thin sheets such as tinplate. The method consists of placing a constant-volume pellet of solder on a tinplate disc together with an excess of

flux, and heating the disc to above the melting point of the solder. The extent to which the molten solder spreads out on the disc is measured with a planimeter and used for comparison. Incorporated in this method is a means for preventing distortion or buckling of the disc during the heating cycle, and provision is made for the introduction of an inert gas to reduce oxidation of the disc or the solder. Correlation between results obtained on this tester and the commercial experience in soldering cans is sufficiently close to allow the use of this test procedure to determine the probable performance of tinplate and solder in high-speed can manufacturing operations.—J. C. R.

Use of High-Frequency Heating in the Tinning of Sheets. G. H. Egri. (Elektr. Verwert., 1947, vol. 21, Feb.–Mar., pp. 250–251 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1997). A description is given of a process adopted in U.S.A. for the tinning of sheets, which has enabled an economy to be effected in the consumption of tin and the production of tinplate to be increased. Some notes are given on the H.F. generators used.

Note on a Protective Grease for Threads Exposed under Corrosive Conditions. M. Cohen, A. C. Halferdahl, and I. E. Puddington. (Canadian Journal of Research, 1948, vol. 26, Section F, Aug., pp. 347–348). The effect of simulated tropical conditions on the seizing up of bolts screwed into a ½-in. steel plate was studied, the threads being protected with different lubricants. With light machine oil the bolts were completely seized up ; with a hypoid lubricant, it was just possible to turn them ; bolts treated with two commercial greases could be turned without much difficulty, and those on which an inhibited aluminium stearate grease had been used were easily turned by hand.—R. A. R.

Formation of Insulating Oxide Films on Electrical Steel. P. L. Schmidt. (Transactions of the American Institute of Electrical Engineers, 1948, vol. 67, Part I, pp. 772–774). A method of providing the insulation between silicon steel laminations made up into magnetic cores of electrical machinery is to produce an oxide coating on them. A process is described by which thin, tenacious, highly resistant films of magnetic oxide are produced on the laminations by heat-treating at 400° to 550° C. in a steam atmosphere containing not more than 0·5% free oxygen. An investigation of the nature of the oxide films at different temperatures in different atmospheres with special reference to their electrical resistance properties is also reported. The low resistivity of oxide films is caused by particles of metallic iron distributed throughout the film. The oxide film formed in conventional continuous annealing and oxidizing processes contains a large amount of ı etallic iron caused by oxidation at above 570° C. at which temperature FeO is formed which later decomposes into Fe_3O_4 and iron. In order to obtain a film not contaminated with metallic iron, the oxidation must take place below 570° C.—R. A. R.

Metallizing in Relation to Marine Engineering. J. B. Stiles. (Transactions of the Institute of Marine Engineers, 1949, vol. 60, Jan., pp. 239–258). The paper describes the metallizing process ; it deals briefly with the equipment used, and considers in some detail the characteristics of the coatings produced. Many applications of the process to marine engineering are described and illustrated.—R. A. R.

Metallizing Failures to Avoid. J. E. Wakefield. (Machinist, 1949, vol. 92, Feb. 5, pp. 1320–1323). Failures of metallized surfaces are usually due to either incorrect application of the process or bad surface preparation. Some typical examples of these types of failures are described. These occurred with a crankshaft, compressor piston rod, a stamping press, and a reciprocating shaft. The methods used in each case to remedy the failures are also described.—R. F. F.

The Further Development of Metal Spraying and Its Spheres of Application. H. Reininger. (Die Technik, 1948, vol. 3, Oct., pp. 437–443). The literature on progress since 1939 in the technique and applications of the metal-spraying process is reviewed. There are seventy-six references.—R. A. R.

Formulation of Corrosion Resistant Paint. J. W. Nee. (Corrosion, 1948, vol. 4, Dec., pp. 599–610). The composition and protection offered by the following types of paint are discussed : (1) Phenolic resins ; (2) courmarone-indene resins ; (3) vinyl resins ; (4) chlorinated rubber ; and (5) special resins (synthetic rubber derivatives). Pigments for primers are also dealt with.—R. A. R.

High-Temperature Ceramic Coatings Developed for Molybdenum. (Steel, 1949, vol. 124, Jan. 24, pp. 59, 82). Experimental tests of ceramic coatings with a zirconia base on parts intended for high temperature service in gas-turbine engines and ram-jets have shown considerable possibilities. J. P. S.

Ceramic Coated Metals for Aircraft Power Plant Applications. R. A. Jones. (Porcelain Enamel Institute : Steel Processing, 1948, vol. 34, Dec., pp. 649–651). The advantages provided by ceramic coatings on certain metal components of aeroplane engines are outlined. Vitreous or porcelain enamel coatings are fused on to the metal and their primary function is to protect it from oxidizing gases and liquids. Unfired ceramic paints generally consist of various oxides or carbides in a soluble silicate vehicle ; they are used when the part cannot be subjected to firing treatment, and for temporary coatings and repairing coatings, or for the control of radiation.—R. A. R.

How to Apply Titanium Enamel to Titanium Steel. J. C. Swartz. (Steel, 1949, vol. 124, Jan. 17, pp. 64–65, 96). The procedure adopted at Westinghouse Electric Corporation, Pittsburgh, for the application of titanium-containing enamels to titanium-bearing steel is described. Conditions for good pickling and nickel deposition, enamel-milling and control, and the firing are discussed.—J. P. S.

Applying Titanium Enamels Direct to Titanium Steels. J. L. Lannan. (Iron Age, 1949, vol. 163, Jan. 27, pp. 77–78). Titanium enamels can be applied directly to titanium steels without the use of a ground coat. Owing to the thinness of the layer, a good finish is required on the parts to be enamelled : a flash nickel coat, of 0·08–0·12 g./sq. ft. of surface is applied. Adherence of the enamel coat is shown by the fact that whereas conventional coatings 0·015 in. thick will " craze " when twisted through 45° in a torsion test, a titanium enamel coating 0·005 in. thick on titanium steel withstands 95°. J. P. S.

PROPERTIES AND TESTS

The Mikrokator Amplifying Mechanism and Its Use in Measuring Lengths and Loads. H. Abramson. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 177–181). A number of Mikrokator instruments are described. The principle of amplification is the same but it is adapted in the different instruments to measure extensions, loads, hardness, and surface finish. Its essential part is a twisted metal strip of rectangular cross-section ; when this strip is stretched the centre portion rotates and this movement can be indicated by a pointer or by a mirror reflecting a beam of light. The rotation of the strip in relation to the increase in the distance which it spans can be increased by providing holes in the centre portion of the strip. Mechanical and other devices are incorporated by which a stable amplification of movement of 200,000 times can be obtained. R. A. R

Standards of Length and Angle for Precision Engineering. H. Barrell. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 182–190). Practical standards of length and angle for precision engineering measurements are described and a review is given of some methods and equipment used for relating the highest qualities of such standards to the fundamental bases of linear and angular measurement.—R. A. R.

A Comparator for High-Precision Measurements of Angles by the Interferometric Method. G. Cassinis. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 191–193).

Metrology in Industry. W. Ruggaber. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 203–210). The purposes and difficulties of accurate measurement in industry are defined and discussed, and a number of instruments of recent design, including the feeler and shadow-projection types, are described and illustrated. R. A. R.

Tensile Tests of Small-Scale Welded Joints. T. D. Tuft. (Welding Journal, 1949, vol. 28, Jan. pp. 41-s–48-s). In the construction of ship models at about $\frac{1}{10}$ scale, material less than 0·05 in. thick is used and Everdur brazing with the carbon arc is used in place of welding. Tests were made to compare the tensile strengths of four types of joint made by Everdur brazing with similar joints made by arc welding. It was found that Everdur joints were not as strong or as ductile as welded joints, though both strength and ductility were

improved when the carbon arc was shielded with helium. Failures in longitudinal **T**, angle, and butt joints of both sets of welds began in the weld beads, and failures in transverse butt joints began in the base metal, except where the weld beads had been filed down before testing.—J. P. S.

Two New Methods for Testing Triaxial Specimens. G. Welter. (Welding Journal, 1948, vol. 27, Nov., pp. 529-s–536-s). Triaxial specimens were made in the form of a three-dimensional cross with screwed ends; notches at 45° to each axis were made so that the stresses were applied to each pair of opposite faces of a cube of ½-in. side. In the first type of apparatus, the stresses were applied by tightening fine threaded nuts, the specimen being enclosed in a cubical box with an extension piece and nut on the ends of each axis. In the second, hydrostatic pressure was applied, the ends of the specimens being attached to pistons working in the walls of a cubical container filled with oil. In the first apparatus, resistance strain gauges were fitted to measure the stresses; in the second, the stresses were deduced from manometer readings of the pressure inside the container. To determine the anisotropy of the material under test (annealed steel) tensile tests on similarly notched uniaxial specimens in the axes of the triaxial cube were taken, a pronounced anisotropy being found. Nevertheless, in both types of apparatus a simultaneous failure in all three axes occurred, the stress being slightly lower than the stress at failure of the notched uniaxial specimen in the weakest direction of the material. The author concludes that the prediction derived from such uniaxial tests, that the tensile stress for fracture increases as the two transverse stresses increase, is not justified. Further tests with isotropic materials are planned.—J. P. S.

Apparatus for Tensile Testing at Sub-Zero Temperatures. E. J. Ripling and G. Tuer. (Product Engineering, 1949, vol. 20, Jan., pp. 103–105). A description is given of a tensile testing machine and equipment for cooling the specimen to temperatures down to that of liquid nitrogen. An insulating flask was made to surround the specimen and the loading members adjacent to it; this was filled with isopentane and its temperature was maintained at the desired level by passing liquid nitrogen at a definite rate through a copper coil at the bottom of the flask. Tests with a 2·75% silicon steel showed that the loss of ductility with decreasing temperature was much more uniform than with mild steel.—R. A. R.

New Method for the Construction of Diagrams of True Stresses. A. I. Chipizhenko. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1469–1475). [In Russian]. Some aspects are discussed of the usual type of true stress–strain diagram, in which the percentage degree of deformation of the specimen is made the abscissa and the stress to which the specimen is subjected the ordinate. A method of constructing these diagrams is proposed which is based on two assumptions: (1) The rupture of the metal occurs as a result of the existence of a limiting stress in the metal, governed by the distortion of its crystal lattice; and (2) a well-tempered metal is in a state of stress through the presence of impurities and crystal boundaries. Expressions are deduced for the maximum resistance to rupture of a specimen in terms of stress and changes in cross-section. The results obtained are shown to be satisfactory for some non-ferrous metals and a number of steels.—S. K.

The Behaviour of Prestretched Structural Steel Beams. R. L. Buchwalter and Y. C. Shiu. (Welding Journal, 1948, vol. 27, Nov., pp. 522-s–528-s). Bending tests on beams which have been previously stretched in tension beyond the yield point of the material, to about 10% elongation, have shown that they could be used to great advantage in constructional work.—J. P. S.

Plastic Behaviour of Wide Flanged Beams. W. W. Luxion and B. G. Johnston. (Welding Journal, 1948, vol. 27, Nov., pp. 538-s–554-s). Tests on welded beams have shown that the actual relation between the load and the radius of curvature of the beam in plastic bending corresponds with theoretical calculations: correspondence is greatest in annealed beams. It is therefore concluded that the behaviour of laterally supported steel beams can be satisfactorily predicted from the stress–strain tensile curves and the usual theory of plastic bending.—J. P. S.

Calculating the Deformation Work for Metals under Ordinary and Impact-Type Tensile Loads. A. Kochendörfer. (Zeitschrift für Metallkunde, 1948, vol. 39, Dec., pp. 376–384). It is shown that the true stress–strain curve for cubic body-centred ferrous metals approximates to a parabola, as is also the case for cubic face-centred metals (*see* Journ. I. and S.I., 1947, vol. 157, Nov., p. 475). The effects of changes in temperature and rate of strain are pointed out and the work of deformation per unit volume as well as the effects of temperature and rate of strain on this work are calculated. Finally, a method of calculating the impact energy from some easily determined data is explained.—R. A. R.

Impact Tests of Pressure Vessels at − 320° F. T. N. Armstrong. (Welding Journal, 1949, vol. 28, Jan., pp. 34-s–40-s). Tests on welded pressure vessels of carbon steel, 8½% nickel steel, and steel to specification AISI 304 (18·67% Cr, 9·03% Ni, 1·35% Mn, 0·09% C, 0·020% S, 0·025% P) were made by dropping weights on to them when they were filled with liquid nitrogen at − 300° to − 320° F. (− 185° C. to − 195° C.); the weight had a tup with ¾-in. spherical radius at the end which struck the vessel. Carbon steel vessels failed by shattering: the 8½% nickel steel, and the AISI 304 stainless steel, although deformed, resisted blows up to 3000 ft.-lb. but a small crack developed in the former at the third blow, which was found to be a shear failure due to the stiffening effect of the backing strip rather than to lack of toughness in the plate. It is considered that the 8½% nickel steel may prove useful in the low-temperature field. J. P. S.

Choice of the Shape of Notch in the Notch-Toughness Test. J. Pomey, A. Cadilhac, and R. Coudray. (Société Française de Métallurgie, Oct. 10, 1947: Revue de Métallurgie, Mémoires, 1948, vol. 45, Nov., pp. 455–467; Dec., pp. 525–540). The authors present and discuss the results of notched-bar impact and notched bend tests on a number of steels including a 2% silicon steel and seven low-alloy nickel–chromium steels, three of which also contained molybdenum, in various conditions of heat-treatment. At first the research was intended to increase the elastic work at the expense of the work of plastic deformation in order to cause brittle fracture, so that the work measured should be related directly to the force at "decohesion." To this end, two lateral notches were cut, so as to suppress the prior work of plastic deformation necessary for the formation of the two lateral cavities on the specimen which usually precede the start of the decohesion fissure and permit the development of suitable triaxial stresses in the case of malleable alloys. Owing to the suppression of this transverse contraction the third stress reaches a much higher value all along the bottom of the principal notch. In order to increase the effect of the notch it was found better to decrease the radius of the bottom rather than to make the notch deeper. In the static notched bend tests it was found that the work of rupture could be divided into three parts, namely, the work of purely plastic deformation, the work of purely elastic deformation, and the work of tearing; the two former develop simultaneously between the elastic limit and the appearance of the fissure under maximum load, and the two latter ensure the progress of fissuration up to fracture. In some cases the elastic work may represent 60–90%, and in other cases the work of tearing may amount to 50–66%, of the total work. The authors think that in brittle fracture the toughness is characterized by high values of both elastic work and work of tearing. In the notched bend test the volume taking part in the elastic deformations is very much greater and the average stresses developed in the mass are much smaller, so that the elastic modulus may be considered to be constant. The supplementary work of tearing is necessary whenever the elastic work stored at the moment of crack formation is insufficient to ensure the propagation of the fissure. The notched impact test appears to consist in the initiation of decohesion followed by complete tearing. The apparent work of tearing is nil in very hard and therefore brittle steels (martensitic structure) and very low in brittle, soft steels (overheated ferrite or annealed structures with intergranular precipitation of hard constituents), whereas it is very high in tough mild steels (fine and regular ferrite) and in longitudinal test-pieces from quenched and tempered special structural steels. The work of rupture under dynamic conditions is almost always much greater than the static work; this is believed to be because in the former case the elastic deformations have not sufficient time to be completed during the impact, so that the metal is less work-hardened and the work of decohesion is greater. The French standard specimen "Unifié Français" seemed

to be less able to show up brittleness than the Mesnager specimen, even though its notch was deeper than that of the latter. The authors propose a new type of test-piece which they claim develops all the characteristics of brittle fracture better than all others. The frontal and lateral notches are 3 mm. deep and 1 mm. wide; the section of the bar at the base of the notches measures 8 mm. deep by 10 mm. wide. A. E. C.

Study of the Plasticity of Sheet Materials. Ya. B. Fridman and A. A. Bat. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1462–1469). [In Russian]. The basic material for experiments made to investigate some factors influencing plasticity of sheet materials was a steel of the following composition: 0·36% carbon, 1·01% chromium, 0·97% silicon, 0·96% manganese, and 0·1% nickel. The steel was in the form of rolled sheet 3 mm. thick, oil-quenched from 880°C; it was brought to a state of high or medium toughness by tempering at 200° C. and 550° C., respectively. Specimens were cut from these sheets for tensile tests and for Erichsen tests. For the former, the specimens were 300 mm. long and were cut out with their major axes either along or across the direction of rolling. To facilitate the fixing of the specimen in the 300-ton hydraulic machine used, special flanges were welded on. Some of the specimens were smooth, whilst others had a 5-mm. hole drilled centrally. It was found that the contraction of the neck for smooth specimens cut in the direction of rolling was 1·5 times larger for medium-tough than for highly tough specimens, the corresponding figure for those cut across the direction of rolling being 2. The plasticity of a drilled specimen, cut across the direction of rolling, was found to be halved on changing the tempering temperature from 550° to 200° C., no such large difference being observed for one cut along the direction of rolling. For the Erichsen tests, smooth specimens, specimens with a central hole 1·7 mm. in dia., and specimens with a cross-shaped hole were used, the maximum depression and load at the appearance of the first crack being noted in each case. Both these quantities were found to decrease on changing from smooth to holed specimens. A third series of experiments, consisting of tensile and Erichsen tests, was also carried out to compare the values of the true elongation for uniaxial and biaxial extension, and showed that this quantity was always smaller for the latter case if the uniaxial extension occurred along the grain of the material, and almost always smaller than that obtained for specimens cut across the grain. Thinner sheet was used for this series, which also included some experiments on non-ferrous metals.—S. K.

Apparatus for the Determination of the Plasticity of a Metal. I. K. Antsiferov. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1486–1488). [In Russian]. Some plasticity tests which have been proposed are discussed, and recommendations are made for making this type of test of greater use to industries dealing with steel.—S. K.

The Effect of Strain-Temperature History on the Flow and Fracture Characteristics of an Annealed Steel. E. J. Ripling and G. Sachs. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2514: Journal of Metals, 1949, vol. 1, Feb., Section 3, pp. 78–90). An investigation is reported, using a low-carbon silicon steel (C 0·031%, Mn 0·12%, P 0·011%, S 0·015%, Si 2·73%, Ni 0·098%, Al 0·23%, Cu 0·116%, Sn 0·008%) to determine (1) the effect of testing temperature on mechanical properties; (2) the effect of prestraining at room temperature on the properties at various low temperatures; (3) the effect of prestraining at various temperatures on the properties at a constant low temperature; and (4) the effect of prestraining at various low temperatures on the properties at room temperature. The prestraining and testing were done on a 10,000-lb. Riehle tensile testing machine and specimens were tested at − 80°, − 100°, − 120°, − 150° and − 196° C. Results are presented in the form of graphs and the following conclusions are drawn: Prestraining small amounts at room temperature caused the retained ductility values at a low testing temperature to pass through a minimum when determined as a function of prestrain. The magnitude of this minimum decreased as the temperature difference between the prestraining and testing temperatures was decreased. At sufficiently large prestrains the retained ductility went through a maximum, after which it again decreased at a rate such that the retained ductility did not become zero until the ductility was completely exhausted in prestraining. With regard to fracturing characteristics after prestraining at a low temperature and testing at room temperature, it appeared that prestraining at any low temperature was no more harmful than the same magnitude of strain at room temperature until the prestrain values were very close to failure. The magnitude of the effects of prestraining at one temperature and testing at another temperature on flow characteristics was smaller for the annealed steel used (body-centred cubic lattice) than for other metals (face-centred cubic lattice).—J. C. R.

Plastic Flow in Cast Iron, at Room and Elevated Temperatures, with Special Reference to Relief of Stress. C. R. Tottle. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A 67–A 75). *See* Journ. I. and S.I., 1948, vol. 160, Dec., p. 445.

Apparatus for the Measurement of Stress. N. P. Bezklubenko. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1498–1499). [In Russian]. A description is given of a simple, dynamometer-type apparatus for the measurement of stress in experiments on deformation. Though capable of giving accurate results, the apparatus has no provision for automatic recording.—S. K.

The Deep-Drawing Properties of Sheets and Their Determination. E. Mohr. (Metallwirtschaft, 1948, Dec., p. 405). The value of the Erichsen test for determining the deep-drawing properties of sheets is critically examined. Very fine grained sheet is generally suitable where annealing between drawings is not practised, but for multiple drawing with intermediate annealing a medium-grained material is better as its structure is more stable. The Erichsen test is recommended for the former case but not for the latter. R. A. R.

Tests of Spherical Shells in the Plastic Range. J. Marin, V. L. Dutton, and J. H. Faupel. (Welding Journal, 1948, vol. 27, Dec., pp. 593-s–607-s). Bursting tests on spherical vessels under oil pressure were used to determine the mechanical properties of a semi-killed "firebox" steel when submitted to combined stresses at low temperatures; plastic stress-strain relationships, yield, ultimate and fracture stresses, and ductility were determined. The test results showed that a decrease in temperature produced an increase in the combined-stress yield and ultimate stresses, and a decrease in the combined-stress ductility, the specimens fracturing into a number of pieces. For room temperature tests stress-strain relationships and ductility agreed with the generalized theory of St. Venant.—J. P. S.

The Distribution of Cold Hardening round a Conical Indentation. F. S. Savitskii, B. A. Vandyshev, and M. V. Yakutovich. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1476–1479). [In Russian]. In the experiments described, a conical indentation was produced by pressure on a specimen of hardened and tempered steel having a fine grained and homogeneous structure. The diameter of the base of the indentation was 4 mm. and the hardness of the area round this was determined with a Vickers hardness tester after mechanical and electrolytic polishing. The indentations were distributed radially round the edge of the hole at 1-mm. intervals, and the results are presented in the form of lines of equal hardness. Similar tests were carried out on compressed specimens and the results of these are presented in the same way and in relation to the deformation.—S. K.

Stress and Strain States in Elliptical Bulges. C. C. Chow, A. W. Dana, and G. Sachs. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2485: Journal of Metals, 1949, vol. 1, Jan., Section 3, pp. 49–58). A report is given of an investigation on the strain state and curvature, exhibited by one circular and two elliptical bulges in steel sheet. The data derived are presented graphically, and the following conclusions are reached: (1) Stress values in elliptical bulges may be analysed by using St. Venant's law of plasticity and the equation for equilibrium of a shell; (2) stress states varying between balanced biaxial tension and close to plane strain can be obtained by bulging thin sheet using the proper die geometry; (3) none of the universal stress-strain relations proposed to date applies accurately in the range of biaxial tension; (4) the discrepancy between bulging and tension values of the stress required for plastic flow may be due to the heterogeneity of strain across the contour of the bulge.—J. C. R.

Resistance Strain Gauges. M. Berry. (Technique Moderne, 1948, Feb. 1 and 15, pp. 41–49: [Abstract] Revue Universelle

des Mines, 1948, Series 9, vol. 4, Dec., p. 724). The author considers equipment for studying the mechanical deformation of metals; such equipment, *i.e.*, the electrical resistance strain gauge, is based on changes in length of a wire, glued between sheets of paper and attached to the part, causing corresponding changes in cross-section and the electrical resistance. Measurement of the resistance enables the linear strain to be calculated.

Bonded Wire Resistance Strain Gauges. C. H. Betts. (Steel, 1949, vol. 124, Feb. 21, p. 115). The use of resistance wire strain gauges, bonded to the specimen, in creep tests is discussed.—J. P. S.

Electric Resistance Wire Strain Gauge Technique in Aircraft Structural Work. L-A. Strömberg. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 118–122). Resistance strain gauges and circuit diagrams for them, with examples of their use on aircraft components are described.—R. A. R.

Some Physical Characteristics of the Wire-Resistance Strain Gauge. E. Jones. (Institute of Physics: Conference on Measurement of Stress and Strain in Solids, July, 1946, pp. 1–26). The author, during a very extensive experience in the use of wire-resistance strain gauges, has observed several factors affecting their stability and accuracy; some of these, relating mainly to the gauge itself are reported. These factors include the behaviour of the gauge backing and layer of adhesive and the effects of changes in temperature, humidity, and waterproofing.—R. A. R.

The Use of Resistance Strain Gauges in Combination, with Particular Reference to the Measurement of Component Loads. F. Aughtie. (Institute of Physics: Conference on Measurement of Stress and Strain in Solids, July, 1946, pp. 27–41). The use of a temperature-compensating gauge, or of two gauges, on opposite sides of a bar and connected in series to give axial strain independent of bending, are two examples of the general case of the use of n gauges interconnected so that any one of the quantities can be determined directly, and the remaining $n-1$ quantities eliminated. The paper discusses this general problem and shows how the necessary circuits can be derived, particularly for the purpose of load measurement.—R. A. R.

High-Frequency Strain Gauges. E. P. George. (Institute of Physics: Conference on Measurement of Stress and Strain in Solids, July, 1946, pp. 42–48). The change of resistance of wires of ferromagnetic material with tension is found to be much greater if the measurements are performed using high-frequency alternating current than if direct current is used. The possible application of this phenomenon to increasing the sensitivity of strain gauges is discussed.—R. A. R.

A Review of Some Recent Developments in Photoelasticity. W. A. P. Fisher. (Institute of Physics: Conference on Measurement of Stress and Strain in Solids, July, 1946, pp. 50–61). The more important developments in applied photoelasticity during the last eight years are reviewed. The use of synthetic resins more sensitive than celluloid is one important advancement. Three quite separate methods of measuring three-dimensional stress distribution are briefly described; these are the 'scattered light,' the 'stress-freezing' and the 'composite model' methods. Then three methods of separating the principal stresses without using the lateral extensometer are discussed; these are the four-point influence method; the method of oblique incidence, and individual measurement of the principal stresses by means of an interferometer of the Mach-Zehnder type. Finally, examples of the application of photoelasticity to special problems are mentioned.—R. A. R.

The Photography of Photoelastic Stress Patterns. H. McG. Ross. (Institute of Physics: Conference on Measurement of Stress and Strain in Solids, July, 1946, pp. 62–64). Techniques for photographing photoelastic stress patterns are described.—R. A. R.

A Note on Time-Edge Stresses in Photoelastic Models. J. W. Fitchie. (Institute of Physics: Conference on Measurement of Stress and Strain in Solids, July, 1946, p. 65). A simple technique for eliminating time-edge stresses in Bakelite BT 61-893, a glycerine-phthalic-anhydride plastic is described. When a model is required a piece is cut from the parent material and then about $\frac{3}{16}$ in. is machined off all the surfaces; it is essential that the model be stored in a desiccator when not being machined or used.—R. A. R.

A Review of Some Strain-Measuring Devices. C. E. Phillips. (Institute of Physics: Conference on the Measurement of Stress and Strain in Solids, July, 1946, pp. 66–72). The measurement of displacements on the surface of a solid is discussed and the characteristics of a number of extensometers are very briefly reviewed.—R. A. R.

The Measurement of Strain in Metals by X-Rays. D. E. Thomas. (Institute of Physics: Conference on the Measurement of Stress and Strain in Solids, July, 1946, pp. 73–82). The possibilities of strain measurement by means of X-rays are reviewed and examples of the techniques for different problems are described. Details of the 'bullet and sleeve' method for repeated and accurate settings of the film–specimen distances are given. For this the X-ray tube is carried on a support which can be approached to the specimen by a fine-threaded screw. At the end of the collimating tube a sleeve is screwed which houses a bullet-shaped member which slides easily but accurately in the sleeve. When the tip of the bullet just touches the specimen (as felt by a feeler gauge 0·0015 in. thick) the film-specimen distance is set. The sleeve is unscrewed and, being shorter than the bullet, the two fall clear. The front pinhole is then screwed on and the exposure is made.—R. A. R.

A Note on Acoustic Strain Gauges. F. B. Bull. (Institute of Physics: Conference on the Measurement of Stress and Strain in Solids, July, 1946, pp. 85–86). Acoustic strain gauges for Admiralty use on ships, and systems for connecting many gauges to a central control point are described. The acoustic gauge operates by measuring the frequency of vibration of a taut wire stretched between the gauge points; the wire is maintained in vibration at its natural frequency by electrical means, and it changes frequency with change of strain between the gauge points.—R. A. R.

Summary of Additional Electrical Methods of Strain Measurement. G. E. Bennett. (Institute of Physics: Conference on the Measurement of Stress and Strain in Solids, July, 1946, pp. 87–110). The principles of methods of strain measurement, using as a basis inductance and capacitance, are explained, and a number of instruments and circuits with which they are applied, are described and illustrated.—R. A. R.

The Adaptation of Mild Steels to the Conditions of Stressing. L. Leloup. (Mémoires de la Société Royale Belge des Ingénieurs et des Industriels, 1949, Series B, No. 1, Jan., pp. 3–34). The range of plastic flow, following after the elastic deformation of iron and mild steels, often permits parts and structures to adapt themselves to stress conditions that would be dangerous to higher-tensile steels. In order to be able to determine the magnitude of the deformation implied by this adaptation the author made a study of the laws of flexion under conditions of plastic deformation; analysis of simple and compound flexion led to the establishment of simple formulæ, which he applies to two special cases where adaptation plays an important part, namely, resistance to the stress concentrations at the edges of rivet holes and the strength of chain links in service and under tests; he calculates the magnitude of the plastic deformation in each case. It appears also that in this process of adaptation there are two clearly defined stages, that of the section, of which the over-stressed fibres shed their overload on to neighbouring fibres, and that of the most heavily loaded region, which frees itself by passing some of the load on to less stressed regions.—A. E. C.

The Measurement of Large Forces. P. Nycander. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 99–104). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 231.

New Vibration-Measuring Instruments. M. Russenberger. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 105–111). A detailed description is given of a new high-frequency pulsator for measuring vibration and damping. The machine produces controlled tensile and compressive forces by means of a magnet. The force is measured optically by a thin-walled tube in series with the specimen, the elastic deformation of which turns a small mirror; this deflects a beam of light across a suitable scale. Some results obtained with it on carbon steel and a cast iron after different heat-treatments are given.—R. A. R.

Modern Vibration Measuring Instruments. J. Severs. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 112–117). Electrical instruments for measuring vibration phenomena are reviewed. The

main limitatons to the extension of the useful working range of vibration pick-ups towards very low and very high frequencies are discussed and a novel precision method of calibrating a velocity-sensitive standard pick-up is described.—R. A. R.

The Designation of Endurance Limit. R. S. Nikolaev. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., p. 1488). [In Russian]. Changes in the symbolical designation of endurance limit are urged for greater clarity.—S. K.

Relation between the Fatigue of Metals and Internal Friction. S. Enomoto. (Journal of the Central Aeronautical Research Institute, Tokyo, 1943, vol. 2, pp. 177–190, 305–324 : British Abstracts, B.I, 1948, Dec., col. 716). The modulus of elasticity and residual strain of annealed mild steel, containing 0·16% of carbon, subjected to repeated torsion were measured using a Schenck-type apparatus. Damping was observed by measuring the temperature of the materials. Little variation was noticed with repeated stresses of 7 kg./sq. mm. until the critical fatigue. The residual strain greatly increased in regions of overstrain. The residual strain of alloys of iron, aluminium, and magnesium, subjected to torsional stress, was also measured, using the freely oscillating wave recorder. Internal friction was due mainly to slight crystal slip.

Crystallographic Phenomena at the Yield Point of Steel and Its Importance Relative to the Fatigue Strength. F. Lihl. (Metallwirtschaft, 1948, Dec., pp. 391–396 ; 1949, Feb., pp. 49–51). After briefly reviewing current theories regarding the breakdown at the upper yield point of the structure of annealed mild steel, the author describes back-reflection X-ray investigations which show that, when a certain stress is exceeded, a subdivision of the crystals takes place along the mosaic block boundaries. This is regarded as a breakdown of a rigid structure within the grains. The increase in strength at the upper yield point is thus caused by the strength increase imparted to the internal network of the grains by the precipitation of alloying elements, or by impurities during cooling. When a certain stress is exceeded, the increased resistance of the mosaic block boundaries is overcome, not simultaneously in all the grains, but in a manner corresponding to the orientation of the individual grains, and independent of any defects in the material. This also explains the drop from the upper to the lower yield point. This drop can therefore only occur when there is a network in the grain ; thus, it does not occur with a pure metal.

Since a subdivision of the grains can occur under fatigue conditions (as is shown by X-ray back-reflection diagrams), there appears to be a connection between the crystallographic phenomena under static and dynamic conditions of stress. The fatigue strength of steel is thus the resultant of two influencing factors, a blocking of the mosaic boundaries on the one hand and an increase in the strength of the mosaics on the other. When the first factor is absent, as with pure metals, the second operates to increase the static strength, the fatigue strength is low and the Wöhler curve falls slowly, becoming horizontal at a very high number of reversals.

Fatigue Testing of Wire. F. A. Votta, jun. (Wire and Wire Products, 1948, vol. 23, Dec., pp. 1117–1123). A description is given of a rotating beam fatigue testing machine developed by the Hunter Spring Co. for making fairly rapid fatigue tests on small-diameter wire. The machine incorporates a synchronous-motor-driven chuck which takes one end of the wire specimen, and an adjustable sapphire bushing to take the other end ; the axes of the chuck and bushing are parallel and the distance between them can be adjusted and very accurately measured. The wire specimen is rotated at high speed while bent in a 180° loop. The results of tests on 0·010-in. stainless steel spring wire and 0·020-in. music wire are among those presented and discussed.—R. A. R.

Effect of Special Nitrides on the Properties of Steels in the Hot State. F. Rapatz, W. Hummitzsch, and H. Krainer. (Verein deutscher Eisenhüttenleute, 1944, Confidential Report No. 74). The results of fatigue tests on weld metal containing different amounts of nitrogen with and without the nitride-forming elements titanium and zirconium are presented and discussed. Specimens containing titanium or zirconium had a markedly higher fatigue strength. Specimens of titanium-bearing steel after various heat-treatments also had remarkably high fatigue strengths when tested at 500° C. It is shown, in general, that very small amounts (a few hundredths of 1%) of carbides of elements which are practically insoluble have a pronounced effect in that they raise the fatigue strength in the hot and cold states.—R. A. R.

Microhardness Testing—A Testing Method of Great Practical Value. E. B. Bergsman. (Industritidningen Norden, 1948, vol. 76, No. 5–6, pp. 29–33). **Microhardness Testing.** E. B. Bergsman. (Anglo-Swedish Review, 1948, Nov., pp. 208–209). **Micro-Hardness Testing—A New Testing Method with Many Practical Applications.** E. B. Bergsman. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 91–96). *See* Journ. I. and S.I., 1949, vol. 161, Jan., p. 72.

Application of the Microhardness Method to the Determination of the Cold-Hardening of the Surface Layers of the Walls of Holes. M. Ya. Freidkin. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1450–1455). [In Russian]. Experiments are described in which the microhardness of layers situated at depths of up to 30–40μ from the walls of holes drilled in steel specimens was measured. A high-speed steel drill, rotating at 2500 r.p.m., was used for drilling a hole 8 mm. in dia. in the normalized steel specimen. The specimen was then cut up so as to provide seven portions, each of which included a part of the cylindrical surface of the hole, different depths of this surface then being removed from each portion by electrolytic polishing. Hardness tests showed that during drilling a thin surface layer is formed which, as a result of the cold-working it has undergone, is considerably harder than the mass of the material.—S. K.

Dissolved Carbon and Nitrogen as Causes of Discontinuous Yielding and Strain Ageing of Mild Ferritic Steel. J. H. Palm. (Ingenieur, 1948, No. 27, Materialenkennis 7, Reprint). Evidence is cited in support of the view that discontinuous yielding and strain ageing are caused by carbon and nitrogen dissolved in the ferrite and not by iron carbide or other precipitates around or in the ferrite crystals.—R. A. R.

Comparison of Notch Tests and Brittleness Criteria. C. J. Osborn, A. F. Scotchbrook, R. D. Stout, and B. G. Johnston. (Welding Journal, 1949, vol. 29, Jan., pp. 24-s–33-s). Three tests are described which are at present in use for the determination of the transition with temperature from shear to brittle fracture : (1) The Kahn tear test (*see* Journ. I. and S.I., 1948, vol. 159, Aug., p. 445) in which the specimen is asymmetrically loaded, and has a drilled hole on the axis of strain joined by a sawcut to the nearer edge. (2) The Penn State test in which a specimen with an Izod notch is supported at its ends and centrally loaded behind the notch, a large hole being drilled in the compression zone and filled with a hardened steel rod. (3) The Lehigh slow-notched-bend test, in which the notched specimen, supported on 1-in. dia. rollers at 7-in. centres, is bent by the application of pressure to a third roller, located behind the notch. The various quantities requiring measurement are indicated in all three cases and it is established that each can be used to determine two types of transition temperature depending upon the brittleness criterion used. The upper temperature T_B, determined by a group of criteria of which the fracture appearance is usually the most satisfactory, is the transition temperature of the material after considerable cold working and under the stress conditions existing at the base of a sharp crack. The lower temperature T_N, 100°–200° F. lower than T_B, may best be determined by using the percentage lateral contraction below the notch as a criterion ; it corresponds to the transition temperature of the undeformed material under the stress system imposed by the machined notch. Of the three notch sensitivity tests, the Lehigh slow-notched-bend test was considered the most satisfactory.

J. P. S.

Temper Brittleness of Plain Carbon Steels. L. D. Jaffe and D. C. Buffum. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2482 : Metals Technology, 1948, vol. 15, Dec.). The authors suggest (1) that plain carbon steels are susceptible to temper brittleness ; (2) temper brittleness develops so rapidly in plain carbon steel that even drastic quenching from a high tempering temperature is insufficient to suppress it ; (3) alloying elements retard the rate of development of temper brittleness. Brief details are given of experimental work with a plain carbon and an alloy steel which support this hypothesis. Previous views that plain carbon steels are not susceptible to temper brittleness are considered to be an erroneous interpretation of experimental data.—J. C. R.

The Evaluation of the Cold-Brittleness of Steel. D. M. Zagorodskikh. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1499–1501). [In Russian]. An account is given of experiments carried out to find the effect of the presence of

various contents of phosphorus on the critical temperature of steel below which rupture is produced with the expenditure of little energy. Impact tests were made at from − 180° C. to room temperature on smooth specimens, normalized from 930° C., of four steels with the following compositions: Carbon 0·15–0·09%; silicon 0·23–0·02%; manganese 0·78–0·48%; sulphur 0·11–0·03%; and phosphorus 0·117–0·412%. It was found that the critical temperature increased with increasing phosphorus content, that corresponding to the highest content of this element being − 5° to − 49° C. It is concluded that the highest permissible content of phosphorus in steel to be used in the coldest climates is 0·25% with 0·06–0·09% carbon.—S. K.

The Lining of Ball Mills. G. Salzmann. (Zeitschrift für Erzbergbau und Metallhüttenwesen, 1948, vol. 1, Nov.–Dec., pp. 240–243). When it became impossible to obtain high manganese steel for ball-mill linings in Germany other materials were tried. The paper describes comparative tests with flame-hardened cast-steel and grey cast-iron lining plates in a ball mill for crushing zinc ores. The losses by wear are compared by weight and by cost of the lining material. The initial weight of the hardened steel lining was 74% of the cast-iron one; its cost was about twice as much, but the rate of wear was one-third that of the cast iron. In terms of cost of material, the loss by wear of the hardened cast steel was slightly less than that of 12% manganese steel.—R. A. R.

Wear Resistance of Wire for Wire Rope. R. S. Brown. (Wire Industry, 1949, vol. 16, Mar., pp. 253–262). *See* Journ. I. and S.I., 1949, vol. 161, Apr., p. 387.

The Effect of Thermal Magnetic Treatment on Magnetization and Magnetostriction Characteristics of Al–Si–Fe Alloy. Y. S. Shur and A. A. Lukshin. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 59, No. 4, pp. 693–695 [in Russian]: Physics Abstracts, 1948, vol. 51, Nov., p. 336). The investigated magnetic alloy probes (5·5% Al, 9·5% Si, the rest iron) are heated for 2 hr. at 950° C., and then cooled in a strong magnetic field of 68 Oersted, a weak field of 1·7 Oersted, and in absence of a magnetic field. The resulting B and $\Delta l/l$ (magnetostriction coeff.) are plotted and show agreement with Shur's theory.

Magnetic Properties of Ferrites: Ferrimagnetism and Antiferromagnetism. L. Néel. (Annales de Physique, Paris, 1948, Series 12, vol. 3, Mar.–Apr., pp. 137–198: Physics Abstracts, 1948, vol. 51, Nov., p. 336). The magnetic properties of a substance containing carriers of magnetic moment arranged on two different lattices are discussed in terms of various parameters. In some cases (ferrimagnetism) the substance behaves at low temperature like a ferromagnetic, but the exchange integrals are negative, so that the saturation magnetization at 0° K is much less than that corresponding to complete parallelism of all the spins. If the carriers are equally distributed between the two lattices the spontaneous magnetization may be zero at all temperatures (antiferromagnetism). In terms of this theory it is possible to explain most of the observed properties of ferrites, and the parameters are calculated in a number of cases. The properties of magnetite, γ-Fe_2O_3 and Mn_2Sb can also be explained. The application of the theory to experimental results on ferrites and antiferromagnetics permits the calculation of the exchange integrals. The values obtained are not coherent but may be explained by supposing the existence of super-exchange forces between atoms, exerted through intermediary atoms.

Tricks with the Supersonic Reflectoscope. F. A. Firestone. (Non-Destructive Testing, 1948, vol. 7, Autumn Issue, pp. 3–19). Some unusual methods of using supersonic flaw-detecting apparatus are described. They include: (1) Finding a flaw which is close to the only accessible surface of the part by cementing the transmitting crystal to a 3-in. block of aluminium or steel and placing the opposite face of the block on the part to be tested. (2) Determining grain size from the relation between the reduction in energy of the initial beam due to scatter by the metal grains. (3) Using a special crystal assembly, called an angle searching unit, to transmit a beam along a plate when the plate edge is inaccessible. (4) Employing a 'ray bender' to send waves into a part at any required angle. (5) Testing thin sheets by sending various types of Lamb waves along it at different velocities. (6) Determining residual stress or incipient fatigue beneath a surface by measuring the velocity of surface waves. (7) Generating shear waves or longitudinal waves by reflection. (8) Measuring plate thickness when one side only is accessible by the spacing between subsidiary reflections. (9) Measuring aeolotropy.—R. A. R.

Weld Testing by Ultrasonic Methods. G. Konried and A. C. Rankin. (Welding, 1949, vol. 17, Feb., pp. 48–57). The principles of the shadow and reflection methods of ultrasonic flaw detection are explained and the advantages and limitations of the instruments available for detecting flaws in welds are discussed. A method reported by Carlin is described; in this the beam of ultrasonic waves is transmitted through a Perspex block, the effect of which is to bend the beam so that whilst if enters the Perspex at 27° from the vertical, it enters the plate at 82° from the vertical. This removes the limitation on the minimum thickness of section which can be tested.—R. A. R.

METALLOGRAPHY

Electron Microscopy in Holland. H. B. Dorgelo. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 211–215). A description is given of the electron microscope designed by J. B. Le Poole for the Laboratory for Technical Physics at Delft.—R. A. R.

A New Electron Microscope: The Philips' EM 100. A. C. van Dorsten, J. B. le Poole, and A. Verhoeff. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 216–218). A description is given of the new Philips' electron microscope the design of which is based on the electron optical system incorporated in le Poole's electron microscope (*see* preceding abstract). The Philips' instrument has two extra lenses to provide continuously variable low and high magnifications in the ranges of 1000 to 6000 diameters and 6000 to 60,000 diameters, respectively.—R. A. R.

Oxide Films Formed on Metals and Binary Alloys. An Electron Diffraction Study. J. W. Hickman. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2483: Metals Technology, 1948, vol. 15, Dec.). Results are presented and discussed of electron diffraction studies of oxide films formed on pure metals and binary alloys. The oxidation of iron showed the presence of three structural transitions: (1) Gamma Fe_2O_3 to alpha Fe_2O_3 at 225° C.; (2) alpha Fe_2O_3 to Fe_3O_4 at 225° to 450° C.; (3) Fe_3O_4 to FeO at 450° to 550° C. In addition the Fe_3O_4–FeO transition was reversible upon heating and cooling.—J. C. R.

Effect of Metallic Segregation on the Cutting Power of High-Speed Steel Tools. K. J. B. Wolfe and I. R. Robinson. (Iron and Coal Trades Review, 1949, vol. 158, Feb. 18, pp. 337–345). In order to ascertain if there were any major segregation in the ferritic portion of austenitized and tempered high-speed steels, the authors utilized the technique of microradiography in which there is prepared a thin section of the steel of the same order of size as the particles of the phases present. It was found practicable to use specimens up to ten times the thickness of the phases in the steel, provided that the specimen is from 0·001 to 0·003 in. thick. A radiograph is then obtained using radiation for which the linear absorption coefficients of the phases present in the steel are markedly different. This radiograph is enlarged and photographed on a conventional transmission-type microscope. The authors give details of their investigations and the results obtained. The following conclusions were reached: (1) Cobalt and molybdenum did not have any appreciable effect on high-speed steel carbide (Fe_4W_2C) segregation, but 4% of vanadium seemed to reduce the size of the carbides, and make the distribution more uniform; (2) the effect of heat-treatment (austenitizing and tempering) was to take the smaller carbides and the heavy metals into solid solution. Precipitation appeared to occur on the remaining carbides rather than by reforming small nuclei, and consequently the range of size of carbides was reduced, *i.e.*, the carbides were more uniform in size. The diffusion of the heavy metals appeared to be more complete than optical microscopical examination suggested: (3) under certain conditions there could exist zones apparently almost devoid of the heavy metals. It was considered that this effect could be caused by non-metallic impurities such as sulphur, phosphorus, or gases. On the other hand that effect could be caused by the presence of non-metallic inclusions of low absorbing power; and (4) it was considered that such zones could act as planes of weakness in a finished tool, especially at the high temperatures developed close to the cutting edge.—J. C. R.

Application of the Method of the Measurement of Electrical Resistance to the Investigation of Austenitic Alloys. G. V. Estulin. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1439–1444). [In Russian]. An account is given of an experimental investigation in which the effects on the electrical resistance of various steels of ageing for periods up to 1000 hr. at temperatures in the 500–900° C. range were determined. Prismatic specimens 10 × 10 mm. in section were used, three or four determinations of resistance being made after each period of heat-treatment. The results are presented graphically as plots of the change in the specific resistance of the specimen against the time or temperature of the ageing process. Both increases and decreases of resistance were encountered, the magnitudes of the changes being relatively small and thus necessitating careful consideration of the experimental errors involved.—S. K.

The Austenite Grain of the Primary Crystallization in Steel. V. E. Neimark. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1445–1449). [In Russian]. In this experimental investigation the factors influencing the primary austenite grain in a steel containing 0·4–0·5% of carbon were studied. To determine the effect on this of the speed of crystallization, bars of the steel were heated in a magnesite crucible in a high-frequency furnace. The steel was kept in the state of liquid + crystals for a given length of time, the current was then switched off, and, when the temperature had fallen to 900–1000° C., the sample was quickly removed from the crucible and partly immersed in water. The size of the primary austenite grains, which were shown by polishing and etching to be bounded by ferrite or troostite, was found to decrease with decreasing time during which the sample had been kept in the two-phase state. The speed of crystallization was also varied by drawing samples of the molten steel into porcelain tubes ranging from 20 to 1 mm. in dia. The size of the primary austenite grains was found to decrease when the diameter was decreased down to 5 mm., but not to be affected by further narrowing of the tube. Study of samples taken from melts at 20°, 100°, and 170° C. above the liquidus line showed that the melting point had little effect on the primary austenite grain. Additions of 0·1% of the deoxidizing elements molybdenum, zirconium, aluminium, vanadium, niobium, titanium, and boron decrease the size of this grain to an increasing extent in the order named. A 1% addition of copper, nickel, or manganese gave a primary austenite grain which was large and edged, in the first two cases, with a coarse ferrite network, and with a troostite network in the third. On investigating the relation between the primary and secondary austenite grains, it was established that, for a steel without additions, 5 hr. heating at 1100–1350° C. resulted in a secondary grain approximating in size to the primary. An addition of 0·05% of aluminium or 0·1% of niobium gave a secondary grain after 5 hr. at 1200° C. which was smaller than the primary, whilst after 1 hr. at this temperature the secondary austenite grain of the steel containing 0·1% of boron was several times larger than the primary. The results of the above investigations are illustrated by a number of micrographs, and their significance and possible applications are discussed.—S. K.

X-Ray Apparatus for Industrial Purposes. W. Ask. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 65–70). [In Swedish]. Descriptions are given of X-ray apparatus for investigating coarse and fine structures. The use of the Geiger-Müller counter is explained. R. A. R.

X-Ray Diffraction As a Tool in Industrial Research and Work Control. O. Alvfeldt. (Instruments and Measurements Conference, Stockholm, 1947, Transactions, pp. 56–64). The principles involved in obtaining X-ray back-reflection diagrams are explained and several examples of the use of the technique to determine unit cell dimensions, atomic positions, and ionic groupings are described.—R. A. R.

The Structure at a Cleavage Surface in Ferrite. E. P. Klier, D. E. Nulk, and F. C. Wagner. (American Institute of Mining and Metallurgical Engineers, Technical Note No. 8 : Metals Technology, 1948, vol. 15, Dec.). A note is presented on an investigation, using back-reflection X-ray patterns obtained on cleavage facets of ferrite grains, to determine the presence or absence of plastic strain at a cleavage surface.—J. C. R.

Homogeneous Yielding of Carburized and Nitrided Single Iron Crystals. A. N. Holden and J. H. Hollomon. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2521 : Journal of Metals, 1949, vol. 1, Feb., Section 3, pp. 179–185). The purpose of this investigation was to determine whether single iron crystals containing either carbon or nitrogen would exhibit inhomogeneous yielding. The authors describe the preparation of large single iron crystals and their decarburization. Some of the crystals were carburized and others nitrided, and were then tested in a hydraulic tensile machine. Data obtained are presented in the form of stress-strain curves and the following conclusions are reached : Carbon or nitrogen causes discontinuous yielding in iron polycrystals, but they do not appear to cause discontinuous yielding in iron single crystals made from aluminium-killed steels. Both elements in small amounts cause an increase in the flow strengths of single crystals, but do not affect the rate of strain hardening.—J. C. R.

Controlled Grain Growth Applied to the Problem of Grain Boundary Energy Measurements. C. G. Dunn. (American Institute of Mining and Metallurgical Engineers, Technical Note No. 9 : Journal of Metals, 1949, vol. 1, Jan., Section 3, p. 72). A direct method for the measurement of interfacial tensions, or grain boundary energies in metals is outlined whereby three-grain specimens are produced in such a way that the equilibrium common grain boundary is perpendicular to the surface of the specimen. The angles to be measured then appear as the grain boundary angles in the surface of the specimen.—J. C. R.

The Effect of Orientation Difference on Grain Boundary Energies. C. G. Dunn and F. Lionetti. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2517 : Journal of Metals, 1949, vol. 1, Feb., Section 3, pp. 125–132). Eleven flat specimens of silicon ferrite each composed of three grains were prepared having (110) planes in the plane of the samples. The common grain boundary point of the three grains was centrally located. Each sample was annealed for long periods of time in the temperature range 1300–1400° C. until further change in grain boundaries seemed unlikely and equilibrium angles apparently had been obtained. After annealing, the grain boundary angles were measured and the relative surface tensions calculated. Since each group of grains contained a similar type of boundary (one where the grains had a 15° difference in orientation) it was possible to calculate all surface tensions on a common basis. A curve was obtained showing the variation of relative surface tension (relative energy in the grain boundary per unit area) with difference in crystal orientation.

The Maurer Diagram and Its Evolution and a New Structural Diagram for Cast Iron. H. Laplanche. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 51, pp. A76–A94). *See* Journ. I. and S.I., 1949, vol. 161, Jan., p. 77.

CORROSION

Corrosion. F. L. LaQue. (Pulp and Paper Magazine, 1948, vol. 49, No. 5, pp. 81–94 : [Abstract] British Abstracts, B.I, 1948, Sept., col. 487). The processes of corrosion and their controlling factors are reviewed, including the acidity of the solution, the presence of oxidizing agents, the effect of temperature and of velocity of agitation, and the action of inhibitors and of concentration cells. Incidental factors influencing corrosion-resistance, *viz.*, surface condition, stress, and heat-treatment, are discussed. Galvanic corrosion is defined and the practical aspects are discussed, the factors affecting it being conductivity, potential difference, polarization, relative area, and proximity of electrodes.

The Protection of Iron Against Corrosion. M. Ragg. (Elektrotechnik und Maschinenbau, 1947, vol. 64, Sept.–Oct., pp. 150–160 : [Abstract] Bulletin and Foundry Abstracts of the British Cast Iron Research Association, 1949, vol. 9, Jan., p. 353). The author discusses the chemical aspects of corrosion and its incidence, with methods of surface protection.

Basic Principles of Corrosion Control by Use of Lime. E. S. Hopkins. (Paper Trade Journal, 1948, vol. 127, TAPPI Section, pp. 296–298 : British Abstracts, B.I, 1948, Nov., col. 637). The principles and practice are reviewed by which the corrosion of iron and steel piping by dissolved oxygen and free carbon dioxide in fairly soft water may be practically eliminated by addition of CaO, the compact Fe_2O_3–$CaCO_3$ deposit formed above the $CaCO_3$ saturation point preventing the diffusion of dissolved oxygen to the metal.

Aspects of Corrosion Phenomena in Pressure Vessels Used for Storage and Transport of Gases under Pressure

P. Schläpfer and A. Bukowiecke. (Schweizerische Verein von Gas- und Wasserfachmännern, Monats-Bulletin, 1948, vol. 28, June, pp. 129–140: Fuel Abstracts, 1948, vol. 4, Nov., p. 44). At temperatures generally prevailing during storage and transport, dry gases, with few exceptions, do not attack appreciably the metal of the cylinders. The part played by moisture, either in the gas or in the cylinders in promoting corrosion is discussed. Corrosion can be reduced to a minimum by thoroughly drying gases and vessels. A bibliography covering 1908 to 1947 is given.

Corrosion-Resistant Steels. A. J. Zuithoff. (Ingenieur, 1948, vol. 60, No. 12, pp. MK 27–28: British Abstracts, B.I, 1948, Sept., col. 489). Steel containing 12–14% chromium and 0·3–0·35% carbon may be hardened and is fairly rust-resistant. Tempering at 450–600° reduces hardness and resistance. Higher chromium contents (16–30%), even with higher carbon content, may cause difficulty in hardening, because chromium narrows the austenitic range, but such alloys are more workable than 18/8 chromium–nickel steel which is austenitic at high temperatures, at which chromium, nickel, and carbon are completely in solution. This condition persists after rapid cooling, although the austenite is stable at room temperature only when the carbon content is $\gtrless$ 0·02%. Usually, however, 18/8 steel contains 0·10–0·15% of carbon so that carbides separate on slow cooling or on reheating at 550–750°. These carbides draw carbon from the whole crystal, but their chromium from the outer zone alone, hence intercrystalline corrosion may occur with risk of unsuspected fracture. Carbide separations may be prevented by adding titanium, niobium, or tantalum to combine with the carbon. Addition of 2–4% molybdenum improves resistance to acids and increases strength at high temperature, but the high cost and difficulty of rolling are disadvantages. Addition of 2% silicon has little effect on corrosion resistance, except in respect of hydrochloric acid. Nitrogen appreciably increases strength, tenacity, and creep limit. Alloys with manganese as a cheap substitute for nickel are finding favour; those with higher chromium and nickel contents show improved resistance to oxidation and mechanical strength at high temperatures, and those containing cobalt (Vitallium) and nickel (Hasteloy) show great strength at high temperatures and good resistance to chemical attack.

Acid-Resisting Steel in the Textile Industry. (Kunstseide, 1941, vol. 23, pp. 259–261: British Abstracts, B.I, 1948, Sept., col. 490). In contrast to the normal 18 : 8 : 2 chromium–nickel–molybdenum steel, a 19 : 9 : 2 steel containing silicon has no tendency to grain-boundary corrosion after welding and is particularly resistant to pitting in halogen-containing solutions, *e.g.*, it remains unattacked after treatment with aqueous NaOCl containing 0·25% active chlorine at 65° for 14 days. The tensile properties of the two steels are similar.

The Intercrystalline Corrosion of Chromium–Manganese Steels. L. Wetternik. (Archiv für Metallkunde, 1948, vol. 2, No. 9, pp. 315–316). Tests were made to ascertain whether L. Schaeben's test for the susceptibility to grain-boundary precipitation of chromium-nickel steels is also applicable to chromium–manganese steels. Nineteen steels representing a wide range of chromium and manganese contents were tested. Strips 2·5–3·0 mm. thick were heated on one side to 1050° C. while the other side was cooled by drops of water; they were then etched in 10% oxalic acid with 0·5% NaCl and in 10% acetic acid with 0·5% NaCl, and tested for ductility by folding. Most of the specimens did not break, and those which did showed no trace of carbides in the grain boundaries. The conclusion was that Schaeben's test was not suitable for the chromium–manganese steels.—R. A. R.

Corrosion-Resistance of Lacquered Iron and Aluminium Cans. R. Grau and H. Buss. (Zeitschrift für Untersuchung der Lebensmittel, 1943, vol. 86, pp. 420–431: British Abstracts, B.I, 1948, Sept., col. 491). The results are given of a considerable number of corrosion tests at room temperature and at 120° (sterilization temperature), using solutions of organic acids, salt solutions of different *p*H and concentration, "Fibrisol" salt solutions, and tap water. The cans tested were made from zinc-coated iron, German iron, French iron, and aluminium (not lacquered). The methods of analysis are also given.

Sodium Hexametaphosphate as an Inhibitor of Corrosion of Iron in Salt Solutions. E. I. Gurovitsch and I. V. Krotov. (Journal of General Chemistry, U.S.S.R., 1946, vol. 16, pp. 1951–1960: British Abstracts, B.I, 1948, Oct., col. 563). The presence of 16×10^{-6} g. of $(NaPO_3)_6$ per cu. m. of refrigerator solution (concentrated aqueous calcium chloride and/or sodium chloride) greatly reduces corrosion of iron and steel pipes. The effect is ascribed to coagulation of the colloidal surface layer of rust, with resultant diminution of its porosity. At the same time its constituent particles undergo reversal of sign, and now behave as anodes with respect to the metal surface.

Corrosion Problems in Water Wells. T. E. Larson. (Corrosion, 1949, vol. 5, Jan., pp. 27–31). The corrosion of pump parts and adjacent areas of tubing in deep water wells is discussed. The solution of CO_2 is facilitated by the high pressure above the pump at the bottom of the well. Tube life is increased by hot application of coal tar paints. Where brass is joined to steel, hand painting the metal for a distance of 2 ft. on either side of the junction reduces the possibility of galvanic attack.—R. A. R.

Experience at Bagnell Dam to Prevent Corrosion of Underwater Steel and Iron. T. White, jun. (Corrosion, 1949, vol. 5, Jan., pp. 25–26). Examples of the application of cathodic protection to prevent the corrosion of the inside of water tanks and other immersed equipment at Bagnell Dam, Missouri, are described.—R. A. R.

Cathodic Protection Applied to Gas and Electric Utility Operations. W. J. Schreiner. (Corrosion, 1949, vol. 5, Jan., pp. 17–24). Descriptions are given of the cathode protection systems applied to buried pipelines and cables in the area served by the Cincinnati Gas and Electric Co.—R. A. R.

Attenuation Equations Applied to Cathodic Protection by Distributed Drainage. E. P. Doremus, G. L. Doremus, and M. E. Parker, jun. (Corrosion, 1949, vol. 5, Jan., pp. 32–36). Equations (called 'attenuation equations') have been derived which show the relationship of the variations in current, potential, and cathodic current density with distance from the point or points where the current is drained from a buried pipeline. Such equations are developed for the case of a pipeline with a number of equally spaced drainage points and methods of determining the optimum distribution of such points are explained.—R. A. R.

Bibliography of Corrosion Subjects. W. P. Noser. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 5–55). This is a copy of Petroleum Bibliography No. 17 which was compiled by the Tulsa Public Library for the National Association of Corrosion Engineers. It is classified into the sections: General, Pipe Lines, Production, Refinery, and Storage, and the items in each section are in alphabetical order of author.—R. A. R.

A Field Experiment with Magnesium Rods. G. R. Olson. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 56–59). Data are presented on the corrosion of buried magnesium rods used for the cathodic protection of buried pipelines.—R. A. R.

Use of Zinc for Cathodic Protection. H. W. Wahlquist. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 61–95). *See* Journ. I. and S.I., 1946, No. 1, p. 16A.

Design and Construction of Tap Changing Transformers for Cathodic Protection. E. G. Goddard. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 96–102). Recommendations are made on the design and construction of transformers to produce the relatively low current and voltage required for the cathodic system of preventing the corrosion of tanks and pipelines.—R. A. R.

The Importance of Internal Corrosion of Tubing. T. W. Johnson. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 103–105). Some examples of the corrosion of pipes in gas-condensate wells are described.—R. A. R.

Some Studies of Waters Produced by High Pressure Wells. W. F. Rogers. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 106–113). Analyses of water from gas-condensate wells are presented and discussed from the point of view of corrosion.—R. A. R.

A Study of Corrosion in Gas and Condensate Wells in the Katy Field, Texas. F. W. Jessen. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 114–126). Data relating to the corrosion experienced in gas and condensate wells in Texas

are presented and examined with a view to determining the causes of the corrosion: the corrosion can be correlated with the rate of flow of gas which in turn is believed to contribute largely to the rate of absorption of carbon dioxide. The ratio of condensed water to hydrocarbon condensate is an important factor in the corrosion of steel by high-pressure gas. A programme for laboratory research on the problem is outlined.—R. A. R.

The Need for a Method of Detecting Internal Corrosion. T. W. McGuire. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 127–132). The urgent need for a corrosion measuring instrument which can detect the progress of corrosion in strings of pipes in high-pressure gas wells, without drawing the pipes, is stressed. Mention is made of equipment for this purpose contained in a tube 7 ft. long and 2 in. dia., which is being tested. Illustrations of the type of corrosion damage encountered are presented.—R. A. R.

Proposed Methods of Detecting Internal Corrosion. T. B. McDonald. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 133–135). A description is given of an instrument for detecting and indicating corrosion pits on the interior surface of gas well pipes. The device to be lowered into the well tubing contains a very small motor which rotates a permanent magnet inside a coil of many turns of fine wire. The magnet and coil are kept in the centre of the tubing and as long as the tube is smooth no voltage is generated in the coil; when they come opposite a pit the effective air gap is increased and the magnetic flux through the coil decreased. The voltage fluctuations are transmitted through wires connected to an amplifier and cathode-ray oscillograph above ground. Tests have proved that the method works in practice and proposals to improve the apparatus are made.—R. A. R.

Estimates of Corrosion Rates by Chemical Analysis. E. A. Brown. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 136–140). Testing samples of water obtained from fittings at the top of gas-distillate wells has proved to be a reliable method of following the progress of corrosion in the pipes. If the water contains 100 to 500 parts of iron per million the corrosion is serious. Graphs of the iron content at three wells are reproduced.—R. A. R.

A Method for Studying Anodic and Cathodic Areas under Cathodic Protection. O. C. Roddey and L. R. Sheppard. (Proceedings of the First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 141–150). Corrosion studies are described in which an anode and a cathode are immersed in an electrolyte and current is supplied from a cell, the corrosion being controlled by variable resistances and the currents measured by milliammeters. The protecting unit is formed by another anode in the same electrolyte to which the first anode and cathode act as cathode. The current required for full protection was determined by ammeter readings using potassium ferrocyanide as an indicator (this turns blue at the corroding anode as long as any iron goes into solution from the corroding anode). This colorimeter indicator is probably more accurate than the weight-less method. The conclusions were: (1) At full protection the corroding anode and cathode have equal interface resistances and polarizations; (2) the electrolyte increases in alkalinity and electrical conductivity with increased protection and with time; (3) electrode interface resistances can and should be eliminated in measuring solution resistivity; (4) tests in limited spaces should not be taken to give absolute values for use in unlimited spaces, but only to show trends; and (5) time is a factor not properly considered in cathodic protection.—R. A. R.

Tests on Buried Pipe Samples Showing Relations of Galvanic Couples to Cathodic Protection Current and Potentials. M. C. Miller. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 151–165). Potentials were measured between buried pipes and three buried electrodes, one 1 in. from the pipe and over the anode, one 1 in. from the pipe and over the cathode, and one 300 ft. from the pipe, as well as between a water pipe 75 ft. away and a $CuSO_4$ reference electrode 300 ft. away. The results pointed to: (1) The desirability of measuring pipe-to-soil potentials before cathodic protection is applied so as to determine to some extent the location of anodic and cathodic areas; (2) the fact that $-0{\cdot}8$ V. to $CuSO_4$ electrode over anodic areas may be just right for protecting steel pipes, whilst much less than $-0{\cdot}8$ V. may be sufficient over cathodic areas; and (3) whether $-0{\cdot}5$, $-0{\cdot}8$, $-1{\cdot}1$ V. or some other potential is required (over the anode or to a remote electrode) depends on the metal in the structure to be protected, the corrosivity of the soil, and the location of the earthing point in relation to the anodic and cathodic areas.—R. A. R.

Applications of Nickel-Containing Corrosion Resistant Alloys in the Petroleum Industry. B. B. Morton. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 179–182). Information is given on the ability of alloys containing nickel to withstand corrosion by sulphur at high temperature, naphthenic acid, HCl, H_2SO_4, HF, and H_3PO_4.—R. A. R.

Basic Principles Involved in the Solution of an Electrolysis Problem. C. H. McRaven. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 203–210). A description is given of the method of making voltage determinations in order to ascertain at which points it would be most advantageous to bond two buried pipelines which are subject to corrosion because of stray earth currents from a nearby electrical transport system. The calculations involved are also explained.—R. A. R.

Coupling Bonding on Natural Gas Pipe Lines. F. J. McElhatton. (Proceedings at the First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 211–219). Natural gas pipelines are constructed with mechanical couplings having rubber gaskets. To apply cathodic protection the pipeline must be a conductor and copper bonds have therefore to be provided at each joint. The paper describes five methods of bonding.—R. A. R.

Refinery Corrosion Problems. Ivy M. Parker. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 220–224). Some examples of the corrosion of tanks, condenser tubes, and other oil refinery equipment, and the steps taken to deal with them are described.—R. A. R.

Economic Factors of the Corrosion Problem. H. C. Gear. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 225–237). The statistical treatment of data relating to repairs, renewals, life, and depreciation of oil-well equipment is explained. R. A. R.

Phillips Petroleum Company Experience in Use of Pearson Electronic Coating Inspector. L. A. Hugo. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 247–252). An apparatus called the "Pearson Electronic Coating Inspector" for detecting faults in the protective coating on buried pipelines is briefly described and the results obtained with it are discussed. One terminal of a 1000-cycle A.C. supply is connected to the pipelines and the other to an earthing rod about 100 feet away. The search equipment for the position of voltage peaks along the pipeline is carried by two men, one carrying the amplifier and indicating meter, and the other is provided with a reference earth connection. Each man has steel cleats attached to his shoes. They walk about 20 ft. apart and the cleats of the second man are connected by a wire to the input of the amplifier carried by the man in front whose cleats are connected to the amplifier shielding.—R. A. R.

Problems in Pulsating Currents. B. Bond. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 253–257). Examples are cited of difficulties which have arisen in the use of cathodic protection for buried pipelines, and some special problems relating to faulty rectifiers, combined direct and alternating currents, and alternating currents are discussed.—R. A. R.

A Proposed Method for Remote Indication of Cathodic Protection Unit Outages. H. P. Griggs. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 260–263). When a number of cathodic protection units for buried pipelines are in operation and inspection of them is difficult it is useful to have a device which will send a signal to a central location when any unit ceases to function. Proposals for such a signalling device are made.—R. A. R.

Prevention of Corrosion in Pipelines and Steam Boilers. P. Van Dongen Torman. (Ingenieur, 1948, vol. 60, No. 2, pp. MK 34–35: British Abstracts, B.I, 1948, Sept., col. 491). The formation of a protective crust derived from the $CaHCO_3$ in the water and iron of the pipes is not

practicable in boilers. Various salts, *e.g.*, $Na_6P_6O_{18}$, Na_2SO_3, chromates, and silicates, or tannins, may be added to the water, or electrical methods used to prevent corrosion. In Germany, NH_4PO_3 has been added to the feedwater, but in Great Britain and the U.S.A. this procedure is considered to be detrimental to non-ferrous parts. Cyclohexylamine has some advantage in this respect, but is too volatile; other amines are being examined.

Preventing Corrosion of Condensate Return Lines. R. T. Hanlon. (Paper to Midwest Power Conference, Apr. 1948: Heating, Piping and Air Conditioning, 1948, vol. 20, May, pp. 86–88: Fuel Abstracts, 1948, vol. 4, Nov., p. 145). This article shows causes of corrosion to be (1) carbonic acid, (2) oxygen, and suggests remedies for neutralization of carbon dioxide and oxygen, such as lime soda softeners and the use of amines, the latter showing good results.

The Prevention of Damage to Central Heating Systems by Corrosion and Boiler Scale. G. Seelmeyer. (Archiv für Metallkunde, 1947, vol. 1, No. 11–12, pp. 487–499; 1948, vol. 2, No. 8, pp. 258–268). The principles of corrosion, scale formation in boilers, and corrosion prevention are explained and full details of many chemical processes for treating boiler water are given.—R. A. R.

Amine Volatility and Alkalinity in Relation to Corrosion Control in Steam Heating Systems. A. A. Berk and J. Nigon. (United States Bureau of Mines, 1948, Technical Paper No. 714). Corrosion tests were run to compare the usefulness of several amines for treating steam systems to prevent return-condensate corrosion. Of the three amines used, cyclohexylamine is very volatile in boiling water and quite alkaline, benzylamine is moderately volatile and moderately alkaline, and morpholine is least volatile and only mildly alkaline. High volatility tends to result in losses during deaeration and to prevent removal of carbon dioxide, thereby increasing its concentration in the system. The higher the concentration of amine required in the system, the greater is the amount required for make-up purposes. The concentration of morpholine tends to decrease during the distribution of steam at low pressures (5 lb./sq. in.); it is not recommended where there are long steam pipelines and high steam losses by condensation. From the standpoint of the quantities used, cyclohexylamine appeared to be less desirable than either morpholine or benzylamine under the chosen conditions. The conclusions apply to the particular plant which operated at 60 lb./sq. in. steam pressure and included a deaerating heater operated at 215–220° F.—R. A. R.

Present Day Aspects of Condensate Well Corrosion. H. E. Waldrip. (Corrosion, 1948, vol. 4, Dec., pp. 611–618). The problem of the corrosion of equipment at condensate oil wells is surveyed; means of detecting the corrosion, and the financial loss it causes are outlined. Finally, methods of combating the corrosion previously reported by W. D. Yale, P. L. Manual, and R. C. Buchan and the answers to a questionnaire regarding the measures taken by twenty-three companies operating condensate wells, are reviewed.—R. A. R.

Prevention of Corrosion in Sour Wells with Organic Inhibitors. W. F. Goss and H. W. Andrews. (Oil and Gas Journal, 1948, vol. 47, Oct. 28, pp. 76–79, 113–114: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1949, Jan., p. 22). The paper describes the use of "Kontols," mixtures of complex organic semi-polar compounds, for protecting sub-surface well equipment.

BOOK NOTICES

BARTOCCI, A. "*I Metalli e l'Acciaio.*" Trattato di Scienza dei Metalli e di Siderurgia. La. 8vo. pp. xx + 1001. Illustrated. Terni: Poligrafico Alterocca Editore.

The author of this book, Prof. Dott. Ing. Aldo Bartocci, is a director of the Terni Steelworks Company and a well-known metallurgist. The first part of the volume deals with metals generally under the following headings: Brief outline of metallurgy; generalities on metals and metallic alloys; transformations in metals; the phenomenon of solidification; methods for the determination of the properties of metals; heat-treatment of metals; effect of plastic deformation on the properties of metals; notes on the principal metal alloys. The second part deals with steel under the following headings: Iron and iron–carbon alloys; production of iron in the blast-furnace; refining of iron in steelmaking; converter practice; open-hearth practice; electric furnace practice; the classification of steels (this gives a brief explanation of the Italian UNI system of classification and compares it with the SAE numbers); carbon steels; special steels; structural steels; steels for special purposes; casting of steel; plastic deformation of steel; heat-treatment of steel; defects in steel arising during production, casting, hot-working, heat-treatment, and from other causes. The text includes numerous illustrations, diagrams, tables, and graphs, and a detailed subject index to both parts.—J. C. R.

BASHFORTH, G. R. "*The Manufacture of Iron and Steel.*" Volume I: "*Iron Production.*" 8vo, pp. viii + 228. Illustrated. London, 1948: Chapman and Hall, Ltd. (Price 21*s.*)

There has long been a need for a simple, up-to-date, and reasonably comprehensive textbook in the English language on iron manufacture. Mr. Bashforth, a lecturer of skill and experience, is well qualified for the task of filling this gap, and the present work should be of the greatest value to technical colleges. His treatment of the subject, though not altogether conventional, is entirely logical; thus, for example, the student does not consider the principles of blast-furnace design in detail until he has acquired a good all-round knowledge of the blast-furnace process. The book is up-to-date in most respects but a minor point of criticism is that some modern developments have been neglected. For example, oxygen-enrichment of blast is not considered (although the effect of blast moisture is noted), acid smelting with subsequent desulphurization of the iron is dismissed somewhat briefly, and some recent work on the treatment of lean ores (particularly the Krupp-Renn process) is not mentioned. Although these processes may not be of immediate application in Great Britain, they are none the less of importance. An excellent and lucid chapter on blast-furnace calculations would have been made still better by the inclusion of a method of calculating top-gas volume and calorific value, which might be of importance in an integrated works. The bulk of the work is naturally devoted to the blast-furnace but there are chapters on electric furnaces and the production of ferro-alloys and alloy cast irons (which include a brief account of cupola practice) and on wrought iron. Most of the diagrams are clear, but some have suffered in over-reduction. References to literature are judiciously selected, and not so numerous as to discourage the student. To sum up, this book, whilst not attempting to supplant the standard reference works on the blast-furnace, is a welcome and much needed addition to industrial literature.—M. A. VERNON.

F.I.A.T. REVIEW OF GERMAN SCIENCE, 1939–1946. "*Physical Chemistry.*" Senior Author, Klaus Clusius. 8vo, pp. 270. Berlin, 1948: Office of Military Government for Germany, Field Information Agencies Technical. [In German]. The majority of the researches outlined in this review, although of great scientific interest, have no direct connection with metallurgy. After chapters dealing with nuclear transmutation and isotopes, infra-red spectra, thermal diffusion in fluids, and specific heat of gases, there is a chapter on the specific heat and heat content of solids, which refers to researches on the atomic heat of metals and also to measurements of the specific heats of iron and steel (0·08–4·1% C). Next follow chapters on calorimetry (including high temperature and bomb calorimetry), photochemical gas reactions, polymerization, heterogeneous catalysis (in which the catalytic effectiveness of a number of metals and alloys is evaluated), colloid chemistry, structure of liquids, macromolecules, adsorption and desorption, and surface and boundary tension. In the final chapter, on physicochemical measurements, reference is made to the determination of densities of molten light metals and alloys up to 800° C.; the results indicate the existence of intermetallic compounds in the fluid state. Koch's work on simple methods of determining thermal conductivity of metals is mentioned, but the

method is not described. Thermometry, pyrometry, and calorimetry are also dealt with, and there is a note on a colorimetric method of determining oxygen in flowing gas. Finally, the use of a combined arc- and resistance-furnace in which ferrosilicon can be prepared, is described.
M. A. VERNON.

F.I.A.T. REVIEW OF GERMAN SCIENCE, 1939–1946. "*General Metallurgy.*" Senior Author, Max Hansen. 8vo, pp. 295. Berlin, 1948 : Office of Military Government for Germany, Field Information Agencies Technical. [In German].

This valuable work is crammed with information of the greatest interest to metallurgists and metal physicists, and one cannot, in a brief review, do more than indicate the fields covered, and pick out a few salient points. The first chapter is on the fine structure of metals and alloys. The space distribution of electrons in the metal lattice has been studied by X-ray methods, and correlated with data on heats of formation of alloys. The precipitation of $CuAl_2$ from mixed crystals was studied ; a similar study on aluminium–zinc–magnesium alloys showed no relationship to stress corrosion. Thermal transformations in steels were shown to proceed by a kind of " chain reaction " in the crystal lattice. A considerable volume of work on the crystal structure of intermetallic phases is reported. Van Bergen has made measurements of the lattice constants of pure aluminium and iron, and other measurements on a variety of non-ferrous metals and alloys of various lattice types, are reported ; they are too numerous to detail.

The second section, on elastic properties, begins with an account of some unpublished work by Köster, who measured the modulus of elasticity, and its temperature coefficient, of a large number of metals from − 180° to 1000° C. or the melting point. Further work was done by the same author, and others, on the effects of composition, thermal and mechanical treatments, and the ferromagnetic state on the modulus of elasticity. Attempts to relate the modulus with the atomic volume and melting-point were unsuccessful.

Alloy structure is next considered. Thermochemical determinations included the latent heat of fusion, change of entropy in fusion of various metals and alloys, and measurements of ΔH, ΔG, and ΔS for various binary alloy systems. Phase diagrams were constructed for no less than 171 binary systems, 71 ternary systems, and five quarternary systems, using different experimental techniques.

The next chapter, on change of state, gives details of researches on the properties of molten metals, the mechanism of crystallization, and diffusion in solid metals. Bückle investigated the latter by making microhardness determinations, having previously determined the effect of composition on hardness. The rate of diffusion of carbon and various other elements in carbon and alloy steels was measured. The oxidation of metals and alloys was studied, in relation to the diffusion process. Thermal transformations in steel, and the hardening process, were examined by a number of workers.

An important chapter on plastic deformation and recrystallization follows. Apart from purely theoretical work, experimental investigations of the deformation of single crystals and polycrystalline aggregates were carried out. Lôrcher confirmed Held's previous work on the discontinuity in the bending curve of single crystals. Oehler has described a microscopical method of following changes in structure during deformation (of polycrystals). Much experimental work on creep and fatigue was done, and Dehlinger developed a theory to account for experimental facts. Most of the work on recrystallization, and its effect on mechanical, electrical, and magnetic properties, is concerned with non-ferrous alloys.

The sixth chapter deals with optical and electron microscopy, and X-ray investigation. In electron microscopy, surface replica, oblique reflection, and emission techniques were used. Mahl and his co-workers studied the structures of aluminium ; steel, in various tempers, was examined by other investigators. Much important work was done in X-ray measurements of elastic strain and stress distribution. X-ray techniques were also used to study the plastic flow of steels. Among other X-ray applications, Schaal measured the residual stress on the surface of chromium–molybdenum steel due to polishing. This amounted to 55 kg./sq. mm., and disappeared at a depth of 0·15 mm.

A long chapter on the testing of materials follows : this covers the theory of testing, and all the customary methods, including non-destructive tests, and machinability tests. A section by Nowotny, on cavitation erosion is of some interest, particularly the experiments of von Schwarz, who found that a fine-grained structure led to increased resistance to cavitation, and examines the relationship between cavitation resistance and mechanical properties.

The final chapter deals with corrosion—theory of corrosion, stress-corrosion, and methods of testing corrosion-resistance. In the theoretical section, phosphate coatings on iron receive much attention.

The review ends with a bibliography.

In conclusion it should be emphasized that the foregoing is necessarily a brief and incomplete summary of a work which is packed with information in a highly condensed form. In view of its importance to metallurgists, it is to be hoped that the preparation of an English translation is under consideration.—M. A. VERNON.

F.I.A.T. REVIEW OF GERMAN SCIENCE, 1939–1946. "*Analytical Chemistry of Inorganic Substances.*" Senior Author, Wilhelm Klemm. 8vo, pp. 326. Berlin, 1948 : Office of Military Government for Germany, Field Information Agencies Technical. [In German].

The subject matter of this volume was originally intended to form part of "*Inorganic Chemistry*" in the same series, but probably because its scope was so wide, it was decided to publish it as a separate volume. Virtually the whole field of inorganic analytical chemistry is covered, and one cannot do more, in the space of a review, than point out some of the salient points of interest to the metallurgist. Like other volumes of the same series, it should be regarded as a bibliographical record and guide to literature, rather than as a critical review. It is, naturally, fully annotated, and nearly all the references are to literature which has already been published in the German technical press ; in some cases, despite the title, as recently as 1948. Interested British workers may therefore find that they are familiar with some of the researches recorded, but this in no way detracts from its scientific and bibliographical value.

After a general introduction, the first section deals with qualitative analysis. This is fairly brief, but it contains an interesting section on chromatographic methods, particularly on the use and requirements of alumina as an absorbing medium, and on the chromatographic separation of the rare earths.

The next section, quantitative analysis, comprises the bulk of the book. Classical methods are dealt with relatively briefly ; they include the use of " Indo-Oxin " for the gravimetric determination of copper, mercury, and nickel, and methods of separating niobium from tantalum. Precipitation of tantalum with phenylarsonic acid and a limited quantity of hydrogen peroxide, in acid solution, is claimed to be complete, and free from niobium, where the Ta/Nb ratio is within the range 1/10 to 10/1. Alternatively, tantalum can be precipitated selectively as sodium hexatantalate. Most of the researches reported are, however, on physicochemical methods—electrolytic, conductimetric, potentiometric (including the analysis of ferromolybdenum, ferrovanadium, ferrochromium, and alloy steels, and the determination of phosphorus in steel), photometric and colorimetric, spectrographic (the analysis of steel receives considerable attention), and polarographic.

A long section follows on routine methods of analysis for various industrial purposes—iron and steel, non-ferrous metals, ores and slags, glass and ceramics, agriculture, and water analysis. A chapter on microanalysis contains a reference to a micro-iodometric method of determining sulphur in steel, and the final chapter, on gas analysis, records work on the analysis of fuel gases, including the use of Freytag's nomograms in producer-gas analysis.

A bibliography is appended.—M. A. VERNON.

LONSDALE, KATHLEEN. "*Crystals and X-Rays.*" 8vo, pp. viii + 199, with 13 plates and 138 figures in text. London, 1948. G. Bell and Sons, Ltd. (Price 21*s.*).

This is an admirable book, which will be of great service to students of any branch of physical science wishing to

learn how X-rays are used in the study of crystals. The historical introduction explains clearly how this branch of study arose. The reviewer was interested to see the quotation from his old teacher, John Perry, who in 1891 referred to our lack of knowledge of the solid state, a defect which has been so admirably remedied in recent years. The types of apparatus now used are briefly described, and there is a clear account of the geometry of crystals. There follows a description—necessarily very short—of the methods used in determining structures, leading to a more theoretical account of the distribution of electrons in a lattice, including the fascinating diagrams representing the Fourier synthesis of the structures of organic compounds. The differences between perfect and real crystals are described, as are the changes produced by mechanical deformation.

All essential matters connected with the examination of crystals by means of X-rays appear to have been dealt with, and the lucid style makes the book an excellent introduction to the subject. Mathematics are used sparingly, and metallurgical students will probably be willing to take the more difficult formulæ on trust, but the discussions of crystal structure can mostly be followed without using more than elementary geometry.

The specific treatment of the structures of metals and alloys is confined to the last few pages, but in that short space it has been found possible to illustrate the principles used in their study and to include an examination of a typical phase diagram—that of the alloys of nickel with aluminium. There are abundant diagrams, and characteristic patterns are reproduced photographically.

C. H. DESCH.

NÈGRE, J. "*Le Soudage Electrique par Résistance—Soudage par points, soudage à la molette, soudage en bout.*" 8vo, pp. 432. Illustrated. Paris, 1948: Publications de la Soudure Autogène. (Price 1350 frs.).

The first four parts of this book deal respectively with the origin of resistance welding, spot welding, seam welding using disc electrodes, and butt welding. A fifth part deals with problems encountered in welding various ferrous and non-ferrous metals. The principles of the different methods of welding are illustrated by the use of diagrams, and photographs of the equipment used are included.—J. C. R.

"*New Ways of Building.*" Edited by E. de Maré, 4to, pp. 235. Illustrated. London, 1948: The Architectural Press. (Price 30*s.*).

This attractively produced book comprises seven chapters by different authors, on the use of concrete, steel, timber, glass, light metals and plastics, and insulation, respectively, as building materials. It is intended not for the expert, but for the architectural or building student, and the subject is therefore dealt with in a somewhat elementary manner. The chapter on steel, by O. Bondy, gives an account of the types and properties of structural steel, describes sheets, tubes, and structural sections, and gives some brief notes on the use of steel in fabricated structures. The chapter on concrete (the longest in the book) gives some information on steel reinforcement. A very useful feature is the bibliography at the end of each chapter; the literature is very well selected. The text is illustrated with excellent photographs and line drawings.

M. A. VERNON.

NEW PUBLICATIONS

ALCACER, J. N. "*Fundición de hierro: fundición gris de alta valor.*" Pp. 326. Madrid, 1947: Dossart.

AMERICAN SOCIETY FOR METALS. "*Properties of Metals in Materials Engineering.*" Cleveland, 1949: American Society for Metals. (Price $5.00).

AMERICAN SOCIETY FOR TESTING MATERIALS. "1948 *Supplement to Book of A.S.T.M. Standards Including Tentatives.*" 8vo, Part I-A: "*Ferrous Metals,*" pp. x + 200; Part I-B: "*Non-Ferrous Metals,*" pp. x + 291; Part II: "*Nonmetallic Materials—Constructional,*" pp. xv + 279; Part III-A: "*Nonmetallic Materials—Fuels, Petroleum, Aromatic Hydrocarbons, Soap, Water, Textiles,*" pp. x + 409; Part III-B: "*Nonmetallic Materials—Electrical Insulation, Plastics, Rubber, Paper, Shipping Containers, Adhesives,*" pp. xiii + 330. Philadelphia. The Society. (Price $20.00).

BOND, E. "*The Facts About Steel,*" 4to, pp. 40. London: Fanfare Press. (Price 1*s.* 6*d.*).

BRAUER, O. "*Der Kupolofenbetrieb.*" 8vo, pp. 80. Berlin. Fachverlag Schiele und Schön. (Price 4.80 DM.).

BURKE, J. E., R. L. KENYON, H. BURGHOFF, and J. T. HOBBS, jun. "*Grain Control in Industrial Metallurgy.*" Cleveland, 1949: American Society for Metals. (Price $5.00).

CISSEL, J. H. "*Stress Analysis and Design of Elementary Structures.*" 2nd Edition, 8vo, pp. 420. New York, 1948: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price 30*s.*).

COOPER, H. J. "*Scientific Instruments, II.*" 8vo, pp. 306. London, 1948. Hutchinson's Scientific and Technical Publications. (Price 30*s.*).

DARDEL, Y. "*Les Conceptions Américaines relatives à la Trempabilité de l'Acier.*" (Centre de Documentation Sidérurgique. Circulaire d'Informations Techniques. Nr. 6, 25 Oct., 1948). 4to, pp. 176, Paris, 1948.

FERGUSON, J. R. "*Technical Metalcraft for Schools.*" London. B. T. Batsford, Ltd. (Price 7*s.* 6*d.*).

HABELL, K. J. and A. COX. "*Engineering Optics.*" 8vo, pp. xiv + 411. Illustrated. London, 1948: Sir Isaac Pitman and Sons, Ltd. (Price 35*s.*).

"*Instrumental Manual* 1949," 4to, pp. vii + 548. Illustrated. London: United Trade Press, Ltd. (Price £3 10*s.*).

JOHÁNEK, J. T. "*Stavba strojů v nomogramech, díl II. Svarované Konstrukce.*" [Nomograms for Machine Design. Part II. Welded Structures]. Pp. 27. Prague, 1948: J. T. Johánek.

JOHNSON, F. "*Metal Working and Heat Treatment.*" Volume III. Pp. 165. Illustrated. London: Paul Elek Publishers, Ltd. (Price 21*s.*).

JONES, W. R. and D. WILLIAMS. "*Minerals and Mineral Deposits.*" 8vo, pp. vii + 248. Illustrated. London, 1948: Oxford University Press. (Price 5*s.*).

KÖHLER, A. "*Das Bestimmen der Minerale.*" Pp. 160. Illustrated. Vienna: Springer-Verlag.

PAGE, S. F. "*Fine Surface Finishing.*" London: Chapman and Hall, Ltd., (Price 16*s.*).

PROSKE, O. "*Analyse der Metalle.*" Band I. "*Schiedsverfahren.*" Hrsg. vom Chemicker Fachausschuss der Gesellschaft Deutscher Metallhütten und Bergleute. 2. Aufl. Pp. 500. Illustrated. Berlin and Göttingen, 1949: Springer-Verlag. (Price 36 DM.).

REITZ, A. "*Mensch und Metall.*" 8vo, pp. 166. Illustrated. Ulm-Donau: Gerhard Hess Verlag. (Price 8 RM.).

ROLFE, R. T. "*Dictionary of Metallography.*" 2nd Edition, 8vo. pp. 300. London, 1949: Chapman and Hall, Ltd. (Price 18*s.*).

SPECIAL AND ALLOY STEEL COMMITTEE. "*A Metallurgica Study of German Aircraft Engine and Airframe Parts, Part II.*" By the Aero Component Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee. Arranged in co-operation with the Committee by C. A. Otto. 8vo, pp. 110. Illustrated. Manchester and London, 1948: The Kennedy Press, Ltd. (Price 10*s.* 6*d.*).

STANLEY, J. K. "*Metallurgy and Magnetism.*" Cleveland, 1949: American Society for Metals. (Price $4.00).

THEWS, E. R. "*Metallurgische Verarbeitung von Altmetallen und Rückständen.*" Band 1. "*Altweissmetalle.*" 8vo, pp. 359. Illustrated. München, 1948: Carl Hanser Verlag. (Price 22.50 RM.).

TÜRCKE, H. "*Totale Riss- und Bruchschäden an Maschinenwerkstücken aus Gusseisen.*" (Schriftenreihe "Aus der Praxis der Autogentechnik," Heft 12). Pp. 49. Halle a. S., 1948: Carl Marhold Verlag. (Price 2 DM.).

VAN DAM, C. F. "*Ijzer en Staal.*" Pp. 116. Baarn, 1948: Uitgeverij Schuyt. N.V. (Price 5.50 fl.).

WEIDLE, R. "*Zur Hartlötung von Gusseisen und Stahl.*" (Schriftenreihe "Aus der Praxis der Autogentechnik, Heft 10). 3. Auflage. Pp. 35. Halle a. S., 1948. Carl Marhold Verlag. (Price 1.15 DM.)

ZAPFFE, C. A. "*Stainless Steel.*" Cleveland, 1949: American Society for Metals. (Price $5.00).

ZORN, E. "*Die Behandlung des autogenen Schweiss- und Schneidbrenners.*" (Schriftenreihe "Aus der Praxis der Autogentechnik," Heft 4). 3. Auflage. Pp. 20. Halle a. S., 1948: Carl Marhold Verlag. (Price 0.75 DM.).